Vol. XXVI. — No. 6. June 1949.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[621 .431 .72 & 625 .285]

The air-cooled railcar Diesel engine,

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The air-cooled Diesel engine has been successfully used in road transport vehicles for the last fifteen years, although it must be admitted that the power outputs of such engines did scarcely exceed 50 H.P. At that time the writer dealt with the design of a four-wheel 56 seater railcar tareing some 9 t. and powered by two four-cylinder air-cooled engines, each developing 60 H.P. (1) (*). Competitive air-cooled Diesels of larger output seemed to be « just round the corner », particularly since water-cooled engines were not then developed to make the utmost of their swept volume, and since the advantages associated with the former were many and the drawbacks view, the small railcar appeared to be the forerunner of an imposing development. However, the car was destined to Spain, the civil war intervened and so did World War II. The latter did sponser an intensive development of air-cooled engines of the petrol variety in England and U.S.A., whilst in Germany air-cooled Diesel engines were feverishly developed for use in tanks from 1942 onwards. As a result of this, considerable information became available which does enable us to consider the advantages or otherwise of air-cooled Diesel engines when used in railcars.

As indicated by the designation, the problem associated with this type of

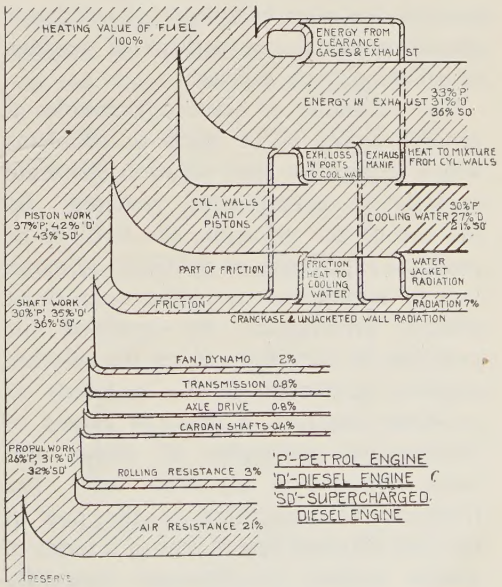
HEATING VALUE OF FUEL 100%
ENERGY FROM CLEARANCE GASES & EXHAUST
ENERGY IN EXHAUST 33% 'P' 31% 'D' 36% 'SD'
EXH. LOSS IN PORTS TO COOL WAT.
EXHAUST MANIF.
HEAT TO MIXTURE FROM CYL. WALLS
CYL. WALLS AND PISTONS
COOLING WATER 27% 'D' 31% 'SD'
PISTON WORK 37% 'P' 42% 'D' 43% 'SD'
PART OF FRICTION
FRICTION HEAT TO COOLING WATER
WATER JACKET RADIATION
SHAFT WORK 30% 'P' 35% 'D' 36% 'SD'
FRICTION
RADIATION 7%
CRANKCASE & UNJACKETED WALL RADIATION
FAN, DYNAMO 2%
TRANSMISSION 0.8%
AXLE DRIVE 0.8%
CARDAN SHAFTS 0.4%
PROPUL WORK 26% 'P' 31% 'D' 32% 'SD'
ROLLING RESISTANCE 3%
AIR RESISTANCE 21%
'P'-PETROL ENGINE
'D'-DIESEL ENGINE
'SD'-SUPERCHARGED DIESEL ENGINE

Fig. 1. — Heat balance diagram of a railcar.

(*) Numbers in parentheses refer to the Bibliography at the end of the article.

engine is mainly one of cooling and it is against this that we shall compare the air-cooled engine with the well-established water-cooled types. In either case the amount of heat to be dealt with by the cooling system is very substantial, the actual magnitudes being shown in Fig. 1. This has been plotted for a 30 ton double-bogie railcar, with a well faired but not streamlined front, powered by a 260 H.P. water cooled engine, provided with a mechanical transmission and running at 130 km./h. (80 m. p. h.). In the case of air-cooled engines the amount of heat dealt with by the cooling system will be about the same, but the power absorbed by the fans will differ. The amount of energy to be dissipated by the cooling system thus amounts to very nearly the energy available for traction and the desirability of reducing the power and space absorbed by the cooling system is therefore obvious.

Before proceeding with a comparative analysis we must establish a basis for a non-dimensional comparison of engines of different types and sizes.

The principle of similitude enables a general survey to be made of problems which require for their solution elaborate analysis or experimental research. By the use of the principle, the findings of practical experience, or deliberate research may be applied to cases other than those directly investigated. By applying the principle of similitude to all the relevant physical properties of the materials or problems involved, a grasp is gained of fundamental principles of design not easily obtained in any other way. The fundamental conception in the line of thought adopted here is that of a series of similar engines of different sizes. By similar engines we understand engines which are of similar types so far as the relation of power to speed and swept volume is concerned.

Whilst the possibilities offered by the use of the principle of similitude in comparing engines have been mentioned by several authors (2), so far as the writer could ascertain the method has not been adopted for a classification and comparison of engines of different designs along the lines indicated below.

For two engines, the linear dimensions of one being the X-multiple of the other we have for bore D and stroke S :

$$S^1 = XS_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and

$$D_1 = XD_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Consequently

$$\frac{S_2 n_2}{30} = \frac{S_1 n_1}{30} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and

$$n_1 = \frac{n_2}{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

so that :

$$n_1 D_1 = n_2 D_2$$

i. e. the product of engine speed n and bore D is constant.

The power output N_e of two engines maintaining the same mean effective pressure p_e is given by

$$\left.\begin{aligned} N_{e_1} &= \frac{\pi D_1^2}{4} \cdot p_e \cdot c_m \cdot C \\ N_{e_2} &= \frac{\pi D^2_2}{4} \cdot p_e \cdot c_m \cdot C \end{aligned}\right\} \quad . \quad . \quad . \quad (5)$$

were c_m in the mean piston velocity and C a factor depending on cycle and number of cylinders. The relation of the power outputs is thus given by

$$\frac{N_{e_1}}{N_{e_2}} = \frac{D_1^2}{D_2^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and consequently

$$\frac{N_{e_1}}{N_{e_2}} = X^2 \quad \ldots\ldots \quad (7)$$

so that

$$X = \sqrt{\frac{N_{e_1}}{N_{e_2}}} \quad \ldots\ldots \quad (8)$$

By substituting the value of X from equation (4) :

$$n_1 = n_2 \sqrt{N_{e_2}/N_{e_1}} \quad \ldots\ldots \quad (9)$$

For $N_{e_1} = 1_1$ the speed n will be the speed of a similar or homologous 1 H.P. engine = the specific speed.

If now one engine is to be geometrically similar to another and be subject to mechanical stresses of the same magnitude, than we must maintain the product

$$n_1 \cdot \sqrt{N_{e_1}} = n_2 \sqrt{N_{e_2}} = n_{sm} \quad \ldots \quad (10)$$

where n_{sm} is the mechanical specific speed. This latter relates either to the power (H.P.) output of a single cylinder or to that of the complete engine. By introducing the value for N_e from equation (5) we have

$$n_2 \cdot \sqrt{N_{e_2}} = \frac{c_m}{2S} \cdot \sqrt{C \cdot p_e \cdot D^3 \cdot c_m}$$

$$= C_2 \cdot p_e^{1/2} \cdot D \cdot c_m^{3/2} \cdot S^{-1} \quad \ldots \quad (11)$$

i. e. the mechanical specific speed is proportional to the 0.5 power of the *m.e.p.*, directly proportional to the bore, the $^3/_2$ power of mean piston velocity, and inversely proportional to the stroke.

From equation (9) we have :

$$\frac{N_{e_1}}{N_{e_2}} = \frac{n_2^2}{n_1^2} \quad \ldots\ldots \quad (12)$$

or

$$N_{e_1} = N_{e_2} \cdot \frac{n_2^2}{n_1^2} \quad \ldots\ldots \quad (13)$$

Introducing the swept volume of one cylinder V [dm^3]

$$N_{e_2} = V \cdot n \cdot C^1$$

so that :

$$n_1^2 \cdot V_1 \cdot n_1 \cdot C^1 = n_2^2 \cdot V_2 \cdot n_2 \cdot C^1$$

or :

$$n_1^3 \cdot V_1 = n_2^3 \cdot V_2$$

so that :

$$n_1 = n_2 \cdot \frac{\sqrt[3]{V_2}}{\sqrt[3]{V_1}} \quad \ldots\ldots \quad (14)$$

For $V_1 = 1$ litre :

$$n_{st} = n_2 \cdot \sqrt[3]{V_2} \quad \ldots\ldots \quad (15)$$

where n_{st} is the thermal specific speed of a similar 1 *l.* engine.

The values of n_{sm} and n_{st} for a considerable number of railcar engines were plotted and found to lay approximately on the lines 1 and 2 of Fig. 2, line 1

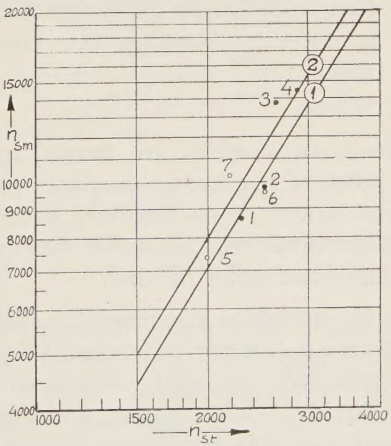

Fig. 2. — Specific speeds of railcar engines.

being representative of modern unsupercharged engine, whilst line 2 is representative for Büchi-turbocharged engines. Line 1 is represented by equation:—

$$n_{sm} = \frac{n_{st}^{1.65}}{45} \quad \ldots\ldots \quad (16)$$

whilst line 2 is given by

$$n_{sm} = \frac{n_{st}^{1.65}}{39} \quad \ldots\ldots \quad (17)$$

For the same net power output, fuel consumption and fire risk, the desirable features of a railcar power plant may be stated as follows:—

1. Reliability.
2. Compactness.
3. Low weight.
4. Small power losses due to cooling system.
5. Easy maintenance.
6. Easy starting from cold and minimum warming-up time.
7. Resistance against the effects of very low or very high air temperature.
8. Resistance against the effects of dust, leaves, etc., blocking the cooling system.
9. Silence.

These requirements are drawn up in the order of importance as they appear to the writer. It is realized, however, that this order will no doubt vary with the individual point of view.

So far as traction experience is concerned there is not much to choose between the reliability of highly developed air —or liquid— cooled engines, under fairly normal operating conditions, but at the present state of the art the price which must be paid for this reliability is very much less so far as the development time and expenditures for liquid-cooled engines of the larger size are concerned. The reason for this is that whilst it is a relatively easy matter to ensure a fairly even temperature distribution over the entire surface of the cylinder barrel of a water-cooled engine, it is an entirely different story so far as air-cooled engines are concerned.

Some of the difficulties that may be expected in the development and production of air-cooled engines may be gathered from the following. Generally speaking the cooling fins should be symmetrical about the cylinder axis, a requirement which would lead to too long engines. The desire for a small overall length would lead to the adoption of unsymmetrical, oval or rectangular fins. Whilst the provision of a suitable close-fitting sheet-metal cowling will result in improved cooling and reduced temperature difference between various points of the cylinder barrel, a temperature difference of up to 60°C. may be encountered between the front and rear of the cylinder (in the direction of air flow). A temperature difference of similar magnitude may be encountered between the top and bottom of the cylinder barrel, whilst the temperature difference between the cylinder head and the base of the barrel may amount to about 70°C. The temperature distribution of a typical radial engine cylinder is shown in Fig. 3.

It is clear from the above that the problem of developing high output air-cooled engines is a very formidable one since the great temperature difference

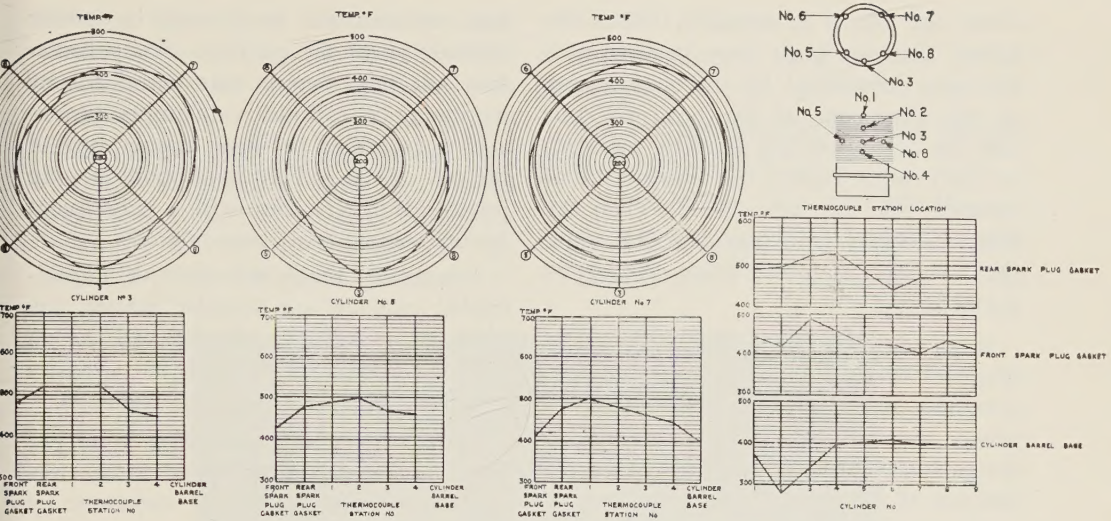

Fig. 3. — Temperature distribution of air cooled engine cylinder.

will result in cylinder distortion, uneven expansion with consequent blow-by and lubrication difficulties, all of which will adversely affect the reliability.

This problem is accentuated by the fact that whilst with liquid cooled engines it is generally possible to maintain an even temperature over the entire cylinder and over the entire working range by controlling the flow of coolant with the help of a thermostat, this can scarcely be the case with air-cooled engines. Here the efficient control of the air flow as a function of temperature may lead to considerable complication. Cylinder barrel « breathing » will thus be encountered both when starting and throughout the entire engine life, a different barrel diameter corresponding to every load. For example, with engine 4 (Fig. 8), a 16-cylinder unit with a cylinder bore and stroke of 135 and 165 mm. respectively, the bore diameter was increased by 0.4 mm. at the top when developing maximum power, this resulting in very unfavourable sealing, particulary in the region of high pressures of the compression and expansion strokes. Some barrel distortion results from shrinkage stresses. Without the head shrunk in position the cylinder barrels of the above mentioned engine will distort along line 1 of Fig. 4,

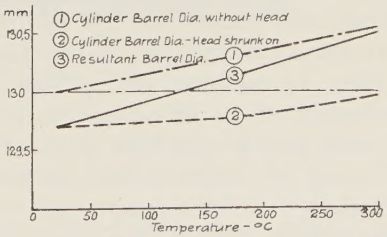

Fig. 4. — Effect of temperature on cylinder diameter.

this distortion being greater for air-cooled than for liquid-cooled engines due to the greater temperature range of the former. The distortion caused by the shrunk on cylinder head when cooling

down are shown by curve 2. Thus the barrel diameter must vary between two extremes determined by the stresses due to the shrinkage of the head (in this case the corresponding diameter amounts to 129.7 mm.) and by the temperature at assembly (in this case 300°C) when the barrel diameter is increased by 0.8 mm., the resultant diameter being shown by curve 3.

It should be mentioned that barrel diameter variations due to different temperatures will follow the variations of piston diameter, so that with suitable design it should be possible to reduce the amount of blow-by.

Considerable difficulties were experienced in the development of air-cooled Diesel engines due to piston seizure and inadequate sealing. In one case remedy was found in the use of Bi-metal piston rings. The poor results obtained with piston rings successfully used in aircraft petrol engines operating under more difficult load conditions indicated that the difficulties encountered were peculiar to the Diesel cycle. The Diesel engine operates with excess air, this permitting a very active oxygen attack on the cylinder oil film. In addition the cylinder wall temperature of an air-cooled engine are very near that of the flash point of the lubricating oil, which is also subject to particularly high temperatures and oxygen concentrations during the compression stroke. As a result of this burning of the lubricating oil during the combustion stroke is a pratical possibility. Whilst during combustion and the subsequent expansion stroke the oxygen concentration will be reduced, there will be still sufficient free oxygen left which, at the prevailing high temperature, may result in further destruction of the oil film. A confirmation of this theory was obtained by increasing the cylinder wall temperature to a level exceeding the flash temperature of the oil. Even at light load conditions an immediate ring seizure with a subsequent piston seizure was encountered.

Conversely the lubrication of liquid-cooled engines is a simpler matter, the piston rings are less affected and the oil need not have a particularly flat viscosity curve, or be so resistant to oxidation.

Somewhat similar difficulties were encountered with a four-cylinder 68 H.P. engine, Fig. 5. These were overcome by

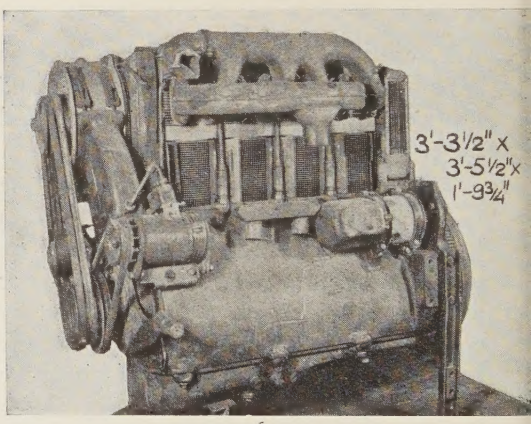

Fig. 5. — Four-cylinder air-cooled engine.

increasing the piston-ring clearance. But even so troubles were encountered due to distortion of cylinder barrels, caused by uneven temperature distribution, this in turn leading to increased blow-by. Since the cylinder temperatures are higher than with liquid-cooled engines, extensive running with smoky exhaust may lead to ring sticking, in turn leading to increased

blow-by, burning of the oil film and ultimate piston seizure, i. e. the air-cooled engine is more sensitive to operation with smoky exhaust.

At present the swept volume per cylinder, particularly with air cooled engines, is limited by thermal considerations, for the greater the cylinder the greater will be the ratio of volume to surface area and the greater therefore becomes the amount of heat released per unit of cooling area. This is shown by the following:

Consider the heat distribution of two similar engines, one with a swept volume of 2 l. per cylinder (Case I), the other with a swept volume of 3 l. per cylinder (Case II).

Assume:—

Power output $N_c = 20$ H.P./l.

Thermal efficiency $\eta_t = 33$ %.

Heat value of fuel $H_u = 11\,000$ k cal/kg.

The amount of heat released per cylinder and hour shall be:

Case I	Case II
$Q_I = 85000$ k cal/h.	$Q = 127500$ k cal/h.

Since about 27 % of the heat content of the fuel will have to be dealt with by the cooling system:

$H_{C_I} = 23000$ k cal/h. $H_{C_{II}} = 34500$ k cal/h.

Assuming now that the heat ultimately absorbed by the cooling medium will be transferred within the area of the combustion space and the upper third of the cylinder barrel, the corresponding areas will be 480 cm.^{2} and 630 cm.^{2} respectively (Borre/Stroke ratio of 0.96).

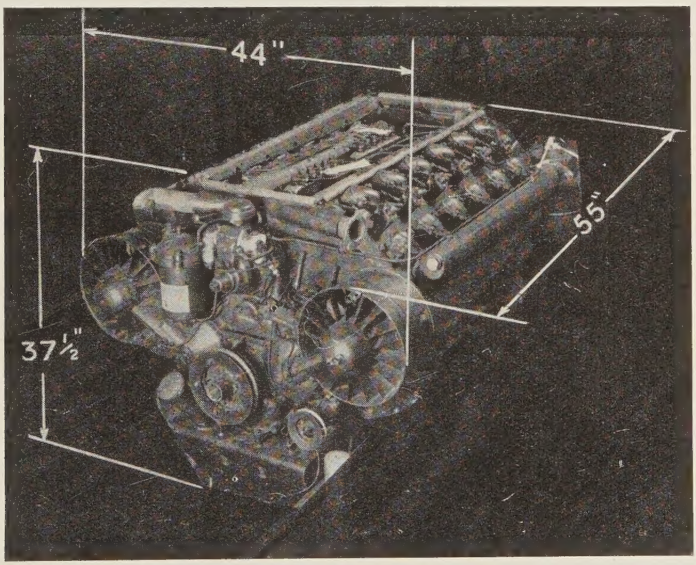

Fig. 6. — Twelve-cylinder air-cooled engine.

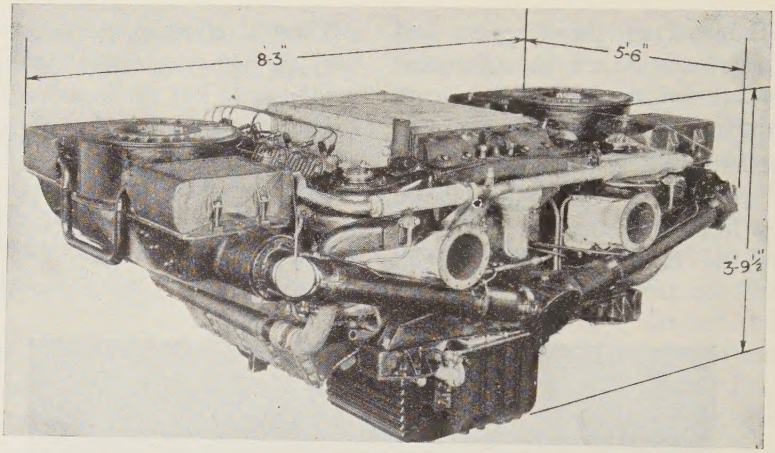

Fig. 7. — Sixteen-cylinder air cooled-engine.

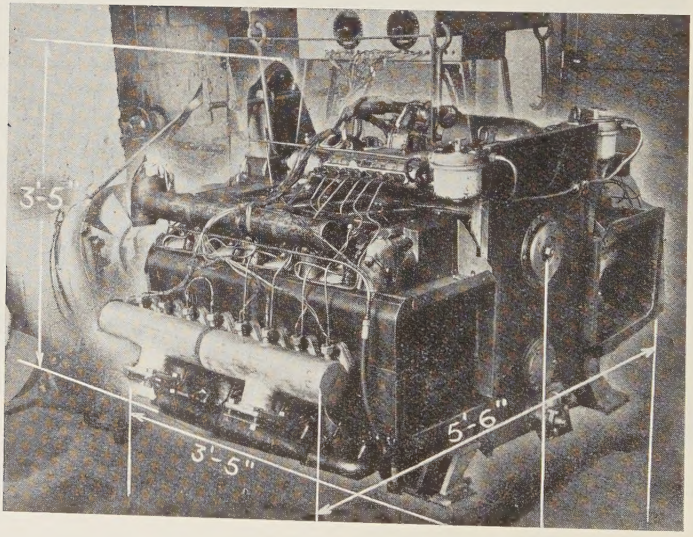

Fig. 8. — Sixteen-cylinder air-cooled engine.

The resultant specific heat throughout will be :

$$h_I = 480 \text{ k cal/(cm}^2\text{) (h)}$$

$$h_{II} = 548 \text{ k cal/(cm}^2\text{) (h)}$$

Thus it will be noted that the larger cylinder is thermally higher stressed than the smaller one, or conversely that the output N_e of the smaller unit can be increased until the heat throughout h of the larger one will be reached.

A certain temperature difference Δt

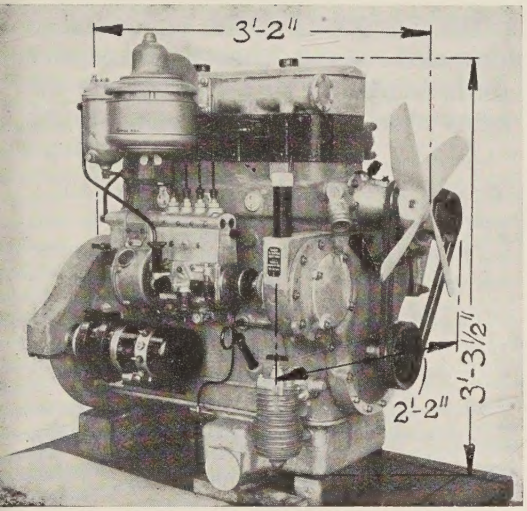

Fig. 9. — Four-cylinder liquid-cooled engine.

between the heat dissipating engine surface and heat absorbing coolant will be required in order to deal with h

$$\Delta t = \frac{H_c}{\alpha A}$$

where:—

α = 0.4 k cal /(cm²) (h) (°C) = Heat transfer coefficient to water stream.

α = 0.018 k cal/(cm²) (h) (°C) = Heat transfer coefficient to air stream.

A = Effective Area (cm²).

Assuming that with water cooling the area in contact with water is 20 % greater than the area in contact with combustion gases we obtain:—

Δt_{Iw} = 120°C Δt_{IIw} = 137°C

For air cooling we can assume the area exposed to the air to be 15 times that exposed to the combustion gases. In this case:

Δt_{Ia} = 178°C Δt_{IIa} = 203°C

This comparison shows that the values of Δt and with them the difficulties of ensuring adequate cooling will rise as cylinder sizes increase. The heat dissipation can be improved by reducing cylinder sizes, at the same time increasing the power output per litre. These considerations were mainly responsible for limiting the swept volume of air-cooled traction engines to about 2.5 litre/cylinder.

It can be shown that the temperature difference across the walls of a combustion chamber and the temperature difference across the piston is proportional to the 0.7 and 0.8 power of the induction air density and the 1.2 power of the characteristic dimension of the engine. Since the indicated power output of the engine rises in proportion to the inlet density and the square of the characteristic dimension, the smallest possible engine

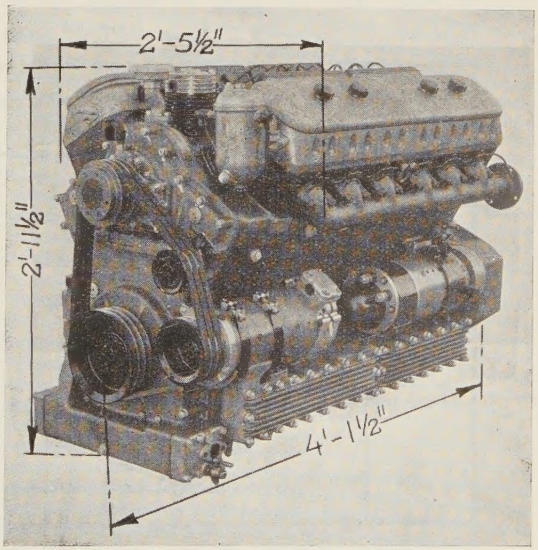

Fig. 10. — Twelve-cylinder liquid-cooled engine.

with a high degree of supercharging shows a considerable advantage for a required indicated power output, so far as cooling and piston temperatures are concerned. The amount of heat rejected to the coolant is also reduced by scavenging. These considerations make supercharging attractive for air-cooled engines.

So far as in line engines are concerned an air-cooled unit will always be longer than a comparable liquid-cooled engine. The reason for this is that with the latter cooling imposes almost no limitations on the minimum cylinder pitch, apart from the need to allow a certain minimum clearance of about 10 mm. between adjacent cylinder walls to ensure adequate coolant circulation and resultant uniform liner cooling. The cylinder pitch needs not, therefore, be greater than about 1.2 times the bore. In an in-line air-cooled engine this would necessarily be in the order of about 1.4 to 1.6.

The area factors of four representative air-cooled and three liquid-cooled engines are indicated in Fig. 11. These are the ratios of the projected engine area to the

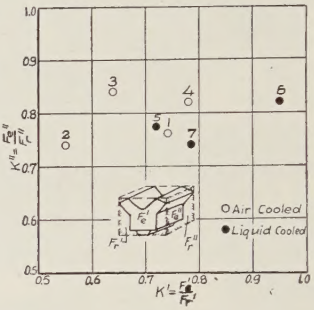

Fig. 11. — Engine area factors.

rectangle surrounding of the engine. The nearer the area factor is to unity, the better use is made of the space occupied by the engine. Engines 1, 2 and 3 are considered in conjunction with their complete cooling system. In the case of engine 3 this comparison is not entirely appropriate

TABLE I — **Engine data.**

Engine No.	Engine Type	No. of Cylinders	Displacement Litres	Max. H. P.	Max. R. P. M.	Weight Ton	Fig.
1	In Line	4	5.35	66.5	2 100	0.47	5
2	Vee	12	15	225	2 250	1.2	6
3	X	16	36.8	760	2 000	2.4	7
4	H	16	37.8	700	2 200	1.57	8
5	In Line	4	5.35	68	1 800	0.44	9
6	Vee	12	16	230	2 200	1.0	10
7	Vee	12	42.8	640	1 400	3.4	—

Note : *Engines 1 to 4 air-cooled (4 does not include fan), 5 to 7 liquid-cooled. Engines 3, 4 and 7 are provided with exhaust-driven superchargers.*

for it has been designed specifically for an existing vehicle and if not for that, more favourable area factors could be achieved. Similar data is also given for three similar liquid-cooled engines 5 to 7.

So far as engine cooling is concerned one might on first consideration expect reduced power losses due to fans, because of the higher temperature differences between engine cylinder fins and the cooling air. In practice however the advantages secured thereby are more than compensated for by the fact that as heat convectors the fins are far less efficient than the radiator matrix. Because of

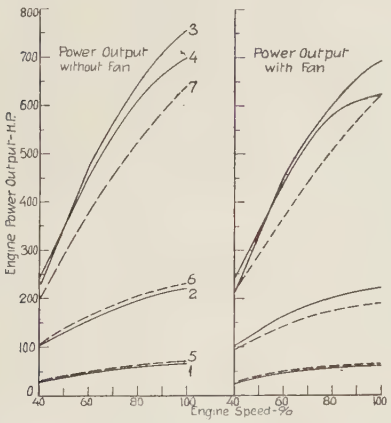

Fig. 12. — Engine performance curves.

this the amount of air required is approximately the same as required by a liquid-cooled engine of identical output, being about 20 qr. per B.H.P. and sec. with the four engines mentioned above. The pressure which must be overcome by the air passing through an air cooled engine is considerably in excess of that encountered in passing through a radiator. Whilst for engines 1 to 4 the pressure drops at maximum speed were 225, 275, 375 and 275 mm. H_20 respectively, for normal radiators this scarcely exceeds about 50 mm. H_20. It is because of this

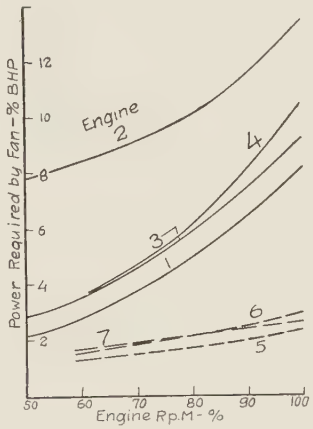

Fig. 13. — Power required by fans.

that the power required to drive the fan amounts to such a large share of the total power developed (Fig. 12, 13). This in turn has an adverse effect upon the fuel

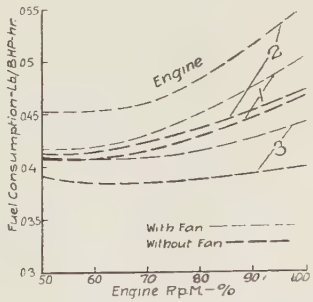

Fig. 14. — Fuel consumption of air-cooled engines.

consumption as indicated by Fig. 14. The corresponding values for the three liquid-cooled Diesel engines are shown in Fig. 15.

The weights of the four air-cooled engines complete with their cooling system is given in Table II. So far as liquid-cooled engines are concerned we must add the weights of the radiators, fans, fan cowls and pipes. This will amount to about 0.05 t. for the 68 H.P. engine, 0.13 t. for the 230 and 0.32 t. for the 640 H.P. engines respectively. These weights were estimated for a cooling system pressurized at 0.35 atm.

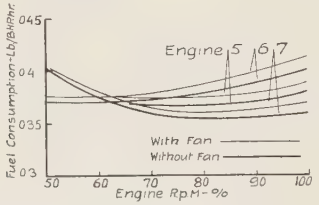

Fig. 15. — Fuel consumption of liquid-cooled engines.

The more rapid warming up of the air-cooled engine ensures quicker starting. The warming up of an air-cooled engine is an easier matter since if need be this can be done directly with the help of a blow lamp. The good conductivity of the metal will bring the heat to the cylinder and pistons. Generally the starting time and resultant fuel consumption is smaller for the air-cooled engine, and whilst the starting of engines of either type becomes practically impossible at extremely low temperatures—unless recourse be made to some extraneous source of heat—use may be made of an air-cooled engine somewhat more rapidly after start than of the liquid-cooled one.

On the other hand whilst with liquid-cooled engines it is possible to warm up the lubricating oil with the help of an oil/coolant heat exchanger, with air-cooled engines the use of thermostatically controlled electric immersion heaters in the oil tank was often found to be desirable to facilitate rapid starting.

With earlier types of air-cooled engines dusts, etc., deposits on the cylinders did not present a cooling problem mainly because of the relatively wide pitching of the fins and the simple cowling used. However with modern engines the fin pitch was progressively reduced, so that at present a fin pitch of 4 to 5 mm. (3 to 4 mm. between fins) is rather rule than exception (A pitch of 4 mm. will be found with machined barrels, whilst a 5 mm. pitch is about the lowest limit for cast units). The cowling has also become more complicated and more « complete », the reason for both being the desire for a higher thermal effectiveness of the fins. We are thus faced with a convection surface very similar to a radiator matrix (only with gills placed at a distance of about 4 mm. from each other instead of 2.5 to 3 as with radiator matrices). The possibility of clogging the inter-fin space — particulary in case of an oil film deposited on the surface — will be very acute. Cleaning is made difficult by the presence of complicated baffles and it will not be easy to find the location of clogged fins, unless a suitable temperature indicating and warning system is provided. The absence of such a system may result in considerable damage to the engine due to local overheating. This can scarcely be the case with liquid cooled engines where an unduly high temperature of the cooling system is sufficient warning for appropriate action.

The liquid-cooled engine is quieter than

the air-cooled one due to the sound dampening effect of the coolant jackets. The greater clearances and expansions caused by the higher working temperatures of the air-cooled engines may, among other things, result in the valve gear becoming a source of noise. This may be reduced by partial enclosing, which at the same time would prevent the settling of dust etc., on the valve gear, and by the use of self-adjusting tappets.

Since the resistance values encountered by the cooling air flow are higher than with liquid cooled units, the fans must be designed for accordingly higher values of pressure coefficients. At the present the practical limit of the pressure coefficient for fans installed in railcars is about $\psi = 0.5$ and when faced with higher values it may be necessary to resort to higher fan speeds or multistage fans. The first measure will obviously rise the noise level, the second is also likely to do so.

The small fan diameters observed on Fig. 5 to 7 are due to the fact that the fans run at speeds of over twice the engine speed.

So far as maintenance is concerned the air-cooled engine should be better than a liquid-cooled unit for it lacks radiators, coolant pump, thermostat, pressure relief valve, water level indicator, coolant evacuation pump, piping and rubber hose connections with all the troubles and tribulations associated with these accessories.

The problem of coolant supply will be done away with for good together with the anxiety of freezing up in cold weather and consequent use of anti-freeze solutions, the supply and handling of which can scarcely be regarded as a welcome addition to the long list of railway stores. The necessity of removing scaled deposits from narrow and tortuous coolant passages will be eliminated and corrosion will also no longer be a problem.

In return the operator will have to face the problem of keeping the cooling fins clean, a requirement which may be found somewhat difficult to fulfil when operating under dusty conditions, particularly if faced with an even small oil leak in the engine compartment. Here attention should be paid to provide easy accessibility when designing the cooling air cowls and when dealing with the installation of the engine in the vehicle.

Since it will be advisable to install a number of temperature feelers at suitable points of the engine, these will present an additional—though minor—maintenance problem.

The possibility of removing worn engine cylinders individually will be of considerable advantage together with the resultant ease of piston replacement.

For further comparison the weight and « boxed-in » space per B.H.P. of the engines dealt with are given in Table II. The weight and space requirements of the cooling system is included in the case of liquid-cooled engines 5 to 7.

The effect of the increased fuel consumption due to the higher power absorbtion encountered with the fans of air-cooled engines may be briefly considered.

As an example consider a 60 ton double-unit car powered by a 600 H.P. engine provided with electric transmission and operating at a maximum speed of 100 m.p.h. The frontal area of the car

TABLE II.

Weight and space requirements of representative engines.

Engine No.	B.H.P. m^3/B.H.P.	Kgr./B.H.P.	Fig.
1	0.283	14.25	5
2	0.24	12	6
3	0.225	7.35	7
4	0.152	4.95	8
5	0.17	15	9
6	0.12	10.8	10
7	0.125	12.7	—

Note : *Engine 4 does not include fan.*

shall be 10 m^2. The tractive resistance of the vehicle is given by the equation (3).

$$W = 1.5\ G + c\left(\frac{V}{10}\right)^2.F\ (kgr.)\ . \quad (18)$$

where G = Vehicle weight (t.).

V = Vehicle speed (km./h.).

F = Frontal area (m^2).

c = 0.225.

For our example W = 665 kgr. or 11.1 kgr./ton, whilst assuming an overall transmission efficiency of 0.75 (this figure includes losses due to auxiliaries) the required power will amount to 525 H.P. It was shown elsewhere (4) that the specific fuel consumption of a Diesel-electric railcar amounts to about:—

B = W (gr./t.km.) = 0.00064W^1 (lb./t.mile)

where:—

W = Tractive resistance (kgr./ton).

W^1 = Tractive resistance (lb./ton).

As indicated in Fig. 13 the power required to drive the fans of air-cooled engines amounts to about 10 % of the nett engine output developed at maximum speed as compared with only about 3 % with liquid cooled engines. To put it in a different way, for the above example with a power/weight ratio of 10 H.P./ton, the difference between air and liquid cooling corresponds to a 27 ton difference in vehicle weight (at 100 m.p.h.) provided of course that the frontal area of the vehicle remains the same.

The effect of the engine upon the design of a Diesel-electric railcar will be gathered from Fig. 16 and 17 showing vehicles powered by engine No. 4 and 7 respectively. The advantages secured by the use of an air-cooled engine in this case are:—

(1) Simple air ducts and fan drive.

(2) Absence of coolant pipes and radiators.

(3) The entire power plant is carried over the bogie. No necessity to stiffen carriage body to carry radiators and fans.

On the basis of the above considerations, it can be stated that the air-cooled engine has the following advantages:—

1. Simplicity of power plant.
2. No need for special coolant.
3. Reduced maintenance requirements.
4. Easier starting in cold weather.
5. Reduced total space requirements.
6. Reduced weight.

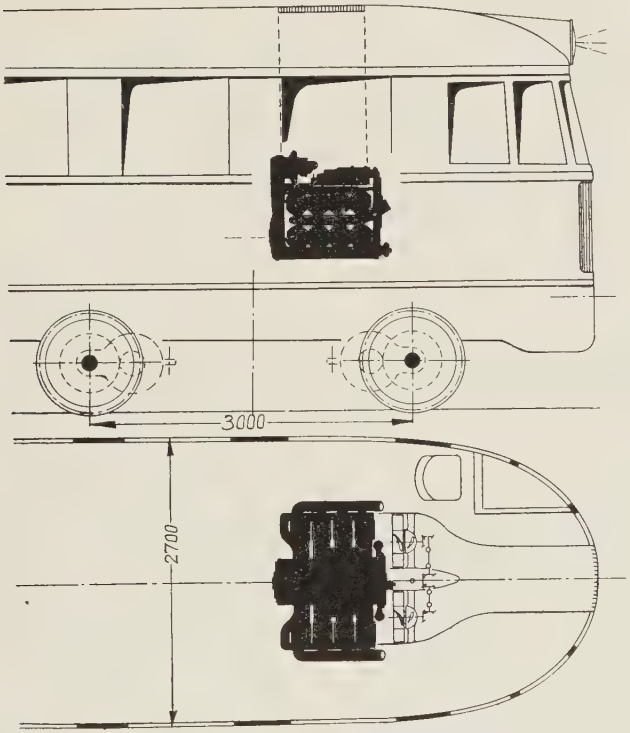

Fig. 16. — Railcar powered by engine No. 4.

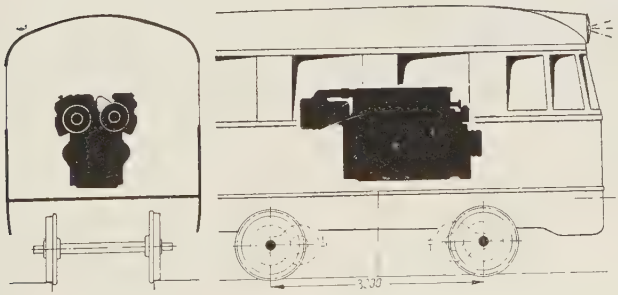

Fig. 17. — Railcar powered by engine No. 7.

The disadvantages at present associated with engines of this type are:

1. Increased power loss due to cooling.
2. Proneness to clogging by dust, etc.
3. Increased loudness level.
4. Special vehicle heating system.

The liquid-cooled engine appears to score on the following points:

1. Small overall cylinder dimensions permitting close spacing.

2. Freedom from restriction of cooling surface area.
3. Flexibility of installation since the cooling surfaces may be placed away from the engine if required.
4. Reduced cooling system power requirements.
5. Greater accessibility of cooling system for cleaning.
6. Simple vehicle heating system.

The main disadvantage associated with these engines is:

The necessity of providing special coolant.

It can thus be concluded that at present the air-cooled engine has as yet many disadvantages so far as railcars are concerned, but if the necessary backing were available both reliable and efficient units of required sizes would probably be available in due time. It is considered, however, that a very considerable amount of development, particularly with regard to increased thermal effectiveness of the cooling system will be necessary before air-cooled Diesel engines can be regarded as thoroughly suitable for traction purposes.

The author gratefully acknowledges the permission given by the Chief Scientist, the British Ministry of Supply, to publish this article. However, the statements made and opinions expressed are the responsibility of the author alone.

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[656 .252]

Efficiency control in large transport undertakings,

by Sir W. V. WOOD,

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Paper read before the Institute of Transport (Metropolitan Section) on October 4th 1948.

(The Journal of the Institute of Transport. November 1948.)

In considering this problem it has always to be borne in mind that, in the control of the efficiency of a transport undertaking, producing for sale not a commodity but a service, there is not the same ready check on its costs which is available to a producer and seller of goods.

A producer for sale can, at short intervals, see what are his production and selling costs under a variety of parts and their relation to the prices he can obtain. There are, of course, various sales by a transport organisation to which this check is applied, but they are by-products of transport and present no difficulty.

Again, where manufacturing and repair work is undertaken by a transport undertaking, costing does not differ in its nature and in its application from that of an engineering company. This was dealt with in detail in papers read at the Buxton Conference of the Institute in 1932, and much more has been done in this direction in the intervening years.

I must divide the provision of the service of transport into two parts: regular services which cannot rapidly be varied in relation to demands, and services to meet demands only. As between the forms of transport there is the further obvious difference that a railway, a dock, a canal, and a tramway have practically constant costs for a large part of the machine they provide, whilst a lorry or bus service, broadly speaking, is charged for its use of the roads by duties on its vehicles and fuel consumed.

These two distinctions overlap and it will be obvious that the regularity of public services for both rail and road passenger traffic involves uneconomic working, at times, in the sense that the receipts from particular services do not cover out-of-pocket expenses, but when services are curtailed on the road side owing to a falling off in traffic demands, there is a greater reduction of costs than in like circumstances on the rail side. The exact opposite applies to increased services to meet increased traffic where the rail vehicles exist, and even where they do not exist, and I remember being convinced 20 years ago that for additional passenger traffic at a peak period of the year lasting only a couple of weeks, the capital and maintenance outlay on additional carriages for that short use was profitable. Whether that would be true now, with much higher capital costs, I could not say. But the war period illustrates my general point; a great increase of freight and passenger traffic was carried despite enemy interference and difficulties in obtaining supplies, with greatly increased net returns because of the large proportion of rail costs which do not vary with the volume of traffic.

I spent some time 20 or 25 years ago in examining this question of variable costs, both at home and abroad, and came to the conclusion that, ignoring long term changes, the fixed costs in Great Britain for all rail traffic, including interest on the capital employed, were 70 per cent of the whole, a large rigid factor being the cost of the track. If, therefore, the cost of 100 units of traffic was £100, the cost of 80 or 120 is not £80

or £120, but

	100 *Units*	80 *Units*	120 *Units*
	£	£	£
Fixed charges ..	70	70	70
Variable charges	30	24	36
	100	94	106
Cost per unit ...	20/—	23/6d. +17 1/2 %	17/8d. —11 2/3 %

In other words, with a fall in traffic of 20 per cent the cost per unit increased 17 $^1/_2$ per cent, and with a rise in traffic of 20 per cent the cost per unit fell 11 $^2/_3$ per cent. These figures might need to be modified a little if recalculated now, because the ratio of the two parts has altered.

Another example is afforded on the railway side by the movement of coal and the raw materials for the heavy trades. While there are more or less regular services for some such traffics, broadly they are served by trains which are run as may be required from day to day or from hour to hour, not unlike road haulage and omnibus travel outside the regular services. When such traffics diminish there is a saving, although far from a full one, in the variable costs, and the reverse if the traffic increases, but little, if any, appreciable variation in the other costs. That, however, does not apply equally to regular passenger train services, as a reduction in the number of passengers travelling does not necessarily result in reduced services. An illustration is the reduction of about 10 per cent in the number of passengers travelling on suburban trains in the peak hours during holiday periods.

For the light traffics, the several million daily consignments with a low average weight, the cost of handling, documentation, and collection and delivery, plus a regrettably large cost in compensation for pilferage, are the chief variable expenses.

These preliminary points explain very broadly why the control of efficiency in transport differs from that in most other businesses.

Budgetary control.

In normal times, a fairly close forecast of the probable traffic volume, mileage and receipts can, from a knowledge of the past, be made for a coming year and divided over the various traffics and over the four-weekly or weekly periods of the year. With that as a base, and with a knowledge of probable prices, the corresponding working expenditure can be estimated in detail by each department.

For the reasons mentioned earlier, a large part of the expenditure is certain, whatever the income may be. A further part will be governed by the mileage and its nature and a further part will be the expenditure which is desirable rather than essential in that year, and in the various departments these parts have very different weights. Each part is checked so far as possible and it is then the responsibility of the management to adopt the proposed outlay in the light of the estimated net result, or to increase or decrease the non-essential parts and earmark specific elements for decrease or increase if the traffics deteriorate or improve.

This budget is not a mere nicely prepared document which is compared with the results some 18 months later, but a practical assembly of the authorised expenditure of each department, which is broken down into each area and each class of expenditure well before the beginning of the year.

The actual weekly or four-weekly expenditure is, throughout the year, compared with the budget estimates in areas as well as in departmental totals. Prices may change and unexpected outlay may be required but, for the current control by the management of the outlay, it is a realistic and effective instrument: in modern terms « budgetary control ».

New works.

Outlay on new works, whether additions or replacements, is a distinct type of expenditure. Each such work is authorised on a concise description of the object in mind with estimates of the gross and net outlay, the division of the net outlay between capital and revenue charges and the net result anticipated from it. The last, and it is the governing factor in most cases, is usually expressed in terms of money including the interest cost of the capital element which may be either positive or negative. After the money is spent, the actual outlay is examined in relation to that estimated, either originally or during the work if some alteration is required, so that the causes of any major divergence can be seen by the management. These arrangements cover not only structural works, but also machinery, rolling stock, and even office equipment.

Nor are the anticipated results overlooked. « Back-checking » of selected works takes place when the results of the whole, and in major cases the parts, are independently examined and considered.

Costing.

Costing is a distinct subject, independent of budgetary control and authorisation of new works, being a critical survey of the expenditure incurred. It does not differ greatly in nature from that in most industries but is of perhaps greater importance in selling transport than in selling goods because, as mentioned earlier, the test of comparative cost and sale prices does not exist.

It concerns not only the making of a particular thing, but of each part of it, and includes repairs, as well as completely new things. Where there is production of the same physical thing in more than one place, the comparison of the parts of each is all important and will sometimes lead to economy in each place, as one with the lower total costs may gain by adopting a particular method of another with higher total costs.

Costing also discloses whether wasteful expenditure is incurred on repairs and that, in turn, forms the basis of a system of measured limits of wear which settles whether a part should be repaired or scrapped—science displacing art.

A further by-product is the time taken in repairing, say, a locomotive in relation to the loss of capital while it is out of service. If the time can be reduced by the adoption of new methods which may cost more than the old but less than the loss of the capital value of the idle locomotive then the change is clearly desirable and is made.

Costing is also a pointer to such economies as those which can often be obtained from replacement of parts by new or reconditioned parts instead of repairing on the spot; again a reduction of capital costs for rolling stock in service which more than offsets the increased cost of holding increased stocks of parts. And costing also points to the all important saving obtainable from standardisation of parts which can be standardised and by the calling in of, say, railway carriages for overhaul at mileage intervals which are measured by the wear of the tyres. As carriages move either way, simple mechanical recorders are unsuitable, and those fitted experimentally to selected carriages merely confirmed the mileage ascertained from the wear of the tyres.

One point which needs to be clear in any costing scheme is the allocation of overheads in detail, and not in total. I remember seeing a tender for a contract which appeared to be too low. Details were asked for and supplied and the error due to the use of total overhead costs was quickly seen and corrected.

Track.

While in most ways what I have said is based on railway rolling stock, it applies generally to road vehicles also, differing in

detail only, but permanent way work is a distinct railway feature. The track, for safety reasons, is subject to continuous examination by the local gangers who are supervised by the area inspectors and the latter, in turn, by the district engineers who keep a history of each section of line since it was last relaid, comparing the rail wear with that anticipated from its previous history and eventually proposing it for replacement. During its life, odd rails, chairs, or sleepers may require to be replaced and the ballast repacked in the normal course and sometimes, when renewals have had to be deferred as in recent years, speed restrictions are imposed. In addition to this local examination, regular tests are made of the condition of the track by a small machine on the floor of a train compartment which records, at various train speeds, any rough riding and exactly where it is, so that a defect, not otherwise obvious, can be dealt with quickly.

When a new type of material or a new design is introduced into the track, it is very closely watched for safety reasons and to see if the advantages contemplated are realised, before it becomes a new standard, and a new standard does not become sacrosanct. The various experiments such as those with heavy section flat bottom rails without chairs, welding of crossings, steel keys between rails and chairs, measured shovel packing of ballast, and concrete sleepers illustrate this on the civil engineering side and the same applies to the mechanical, signalling, telegraph, and other sides.

Complete renewal programmes are settled well in advance in the same way as new works and entirely on the facts. The causes of wear vary greatly throughout the country; but year by year the overall age of the track renewed averages about 21 $^1/_2$ years. Density of traffic, speed, climatic conditions, the nature of the road bed or tunnel and even the presence of chemical fumes are all factors governing the various lives in this average, which range from 5 to 50 years. The rails taken out of first class track are not scrapped as 75 per cent of them are re-used on secondary or branch lines and finish their railway use on sidings, these further uses being planned like the first one. The same applies in a lesser degree to the other materials such as the sleepers, chairs and fish plates, but over all, for £100 worth of new material put in, £44 is recovered. The importance of costing for such work does not need elaboration.

When the renewal programme is settled, the types and quantities of each material required for each part are determined and the actual dates for each job are settled with the Operating Department and it is then a matter for the Stores Department to arrange for the supply of the materials to the depots or the points required and to sell the ultimate residual materials for other uses or as scrap.

Stores control.

Stores control for all materials is necessarily elaborate. Central purchasing and responsibility for issues to the consuming centres over a wide field is common and the aims must always be to control stocks to the economic minimum and, as far as possible, arrange for supplies to go direct from the seller or manufacturer to the point of use or consumption, so as to avoid intermediate handling. The economic minimum stock is settled by experience and must avoid valuable plant being held up for new parts required for construction or repair purposes. The assembly on the spot to a time-table for all the parts for renewing permanent way, to which I have referred, is an illustration of this need, and another is the holding, at convenient places, of parts which are interchangeable so as to permit the quick repair of damaged or worn out parts. The need for control of issues is also important for consumable things as distinct from materials and parts for engineering purposes; a need not lessened by present scarcities for both rationed and

unrationed things which can be used for household purposes!

Apart from the purchase and issue of stores, the control of materials inside a workshop or along the permanent way remains the responsibility of the Stores Department. For example, when a locomotive boiler comes off a locomotive for repair it is replaced at once by a new or reconditioned one at stock price. The displaced one is brought into stock at its depreciated value and, if later on it is repaired, the expenditure for the purpose is added to its stock value. This practice permits an even flow of the work on repairing boilers and brings a further economy. A third department is concerned in this and other shop activities, the Accountant's, which acts as the recording angel (although not always so regarded in a shop) not only on transactions such as this but in the costing processes.

I shall not attempt to deal with the many sides of accounting work, but the following quotation from a railway journal which I read lately is apt:— « The accounting departments of the railroads now more than ever are essential parts of management and an indispensable factor in determining policy. If they ever were considered mere scorekeepers after the event, that time has passed, and their difficulty now is to provide quantitative data, properly screened and evaluated, fast enough to meet the needs of the decision-makers ». There is ample evidence in this that the writer was an American.

Traffic working.

On the traffic side, the types of control are very different from those I have been discussing.

The public time-tables which you see are the third stage of the real time-table. They begin with plotted diagrams showing for each district the course of each train, vertically for each quarter mile of track and horizontally for each two minutes of the 24 hours of the day. They cover passenger and freight trains which are booked and also locomotive movements without trains, and when other trains are required, particularly the less regular freight trains which are governed by output only, paths for them can readily be made from the diagrams so as not to conflict with the booked paths. Stage two is the working time-table which includes not only all scheduled trains and « light » locomotives, but also the provisions of locomotives and the arrangements for changes of train crews en route. The third stage is the public time-table, confined to passenger trains other than scheduled relief trains and trains of empty carriages. That puts it simply, perhaps too simply, but settling the location of locomotives, the preparation of them to be ready for the many train movements required, the rostering of staff to work them and a margin of locomotives, carriages and train crews to meet contingencies is perhaps the most complex part of railway work. How it functioned during the war, you all know at least something about.

Wagon control is another all-important matter. There is not a balanced movement of traffic each way, for example from and to the coal pits, and thus certain areas always accumulate stocks of empty wagons. Early each morning, in each district the prospective needs of each yard are estimated and telephoned to the district controller, who then knows the surplus or deficiency in his district and arranges any intra-district transfers required to balance each yard. At a fixed time, each district controller in a division attends a telephone conference with the divisional controller at which surpluses and deficiencies in the division are compared and any necessary exchanges between districts are settled. The process is then repeated between the divisions as regards the overall position of each, and again as regards the Region (to use the new term) as a whole, and, lastly, between the Regions as a whole so that,

before 10.0 a.m., all the transfers of empty wagons and the points between which they are to move have been decided. The actual movements by special trips or otherwise inside the districts, the divisions, the Regions, and between the latter, with the aid of the train diagrams, have already commenced, the depots know what locomotives to provide and the signalmen know what trains to expect.

The control of passenger carriages is a simple matter compared with that of wagons, because for scheduled trains they very largely run in sets for balanced movement each way, although some of these trains may have carriages attached or detached for special demands or the reverse. I saw a few days ago a letter to a newspaper pointing out that on a particular train from a port the loading was very light and suggesting that, as the prospective number of passengers must be known, the train should have been shorter. Possibly, but the critic did not appreciate that the carriages were required for a return movement as there is not a balanced flow of passengers each way all the time. Anyone who travels from, say, Brighton to London about 5 o'clock on a warm Saturday afternoon will find plenty of vacant seats, but not perhaps if the weather has broken. A little thought will show that the capital cost of providing stocks of carriages and accommodation for them at all terminal points, so as to make the number of carriages on each train those actually required from day to day, would be very much greater than the cost of hauling even completely empty trains to balance the requirements of passengers. On the four main line railways in 1938 the average number of passengers per train, weighted for distance, was 70, little more than the number of seats in one carriage, and even in the peak year of 1945, with a great reduction in the trains run, it was only 170, which is less than the seating capacity of three carriages. It has to be remembered that some 25 per cent of the receipts from passenger train working came from charges for mails, parcels, and dining car services.

The Motive Power staff, who have to arrange the movements of both passenger and freight trains, whether loaded or empty, must have a margin of locomotives and crews ready to meet as far as possible the varying demands upon them. By locomotives I mean various types of locomotives, and a temporary surplus of any type over this marginal requirement is stored in serviceable condition, the preparing of them for use not being permitted, whatever may be the temptation to the depot foreman. The forecasting of the needs of each depot to ensure that the proper type of locomotive is provided for each train and to avoid undue surpluses is not a matter for an amateur.

« Garage » repairs, a term not liked by the depot staff, are a miniature of those in the shops, and for each locomotive there is a complete record of mileage, coal and oil consumption, and of all casualties and their causes, a casualty being an involuntary stop lasting more than two minutes. This is not merely a paper exercice, but the basis of a causation analysis to throw up defects in all locomotives used throughout the system, whether due to physical or human reasons, or to quality of coal or lubricants. A persistent change in the quality of coal may require the re-design of the grate and such things as a shortage of rape oil or the inclusion of stones in the fuel may cause irate passengers to complain of train delays; but their complaints are as nothing compared with the complaints of those who have to run the trains and take great pride in working « on time ».

Another major traffic task is in the transfer of goods from the premises of the consignor to the wagons and from them to the consignee. You may have seen all-company figures showing the man hours per ton of goods loaded and unloaded, but these totals are of little practical use because the nature of the traffics varies between the stations and

the hours per ton vary in the ratio 1 : 5. The practical use is confined to the figures for each station and they are closely watched, and the same applies to the cartage statistics. I doubt if there has been any traffic problem upon which more experiments have been made than that of finding the cheapest way of transferring containers to and from road vehicles.

Job analysis.

In recent years, what has become known as « job analysis » has been greatly developed. It is the examination by a specially trained staff of *all* the factors in the working of, say, a section of track, a marshalling yard, a goods station, or a motive power depot. Detailed time studies play an important part in this work and point the way to new methods and to structural alterations which may be required to meet the ever changing traffic requirements. New marshalling yards, goods depots, re-signalling schemes, the progressive repair systems for rolling stock, colour light signalling, and automatic signal warnings to drivers, are examples of the results of these types of research.

Scientific research.

Scientific research is quite distinct, except in so far as it is the instrument in solving some particular problems as the consultant of the various departments. Its work is mainly in the laboratories with problems of a chemical, textile, paint, and metallurgical nature peculiar to railways and the organisation is in close contact with the research bodies of the Government, the Universities, and of industry.

Road transport.

While the problems of road transport, apart from track and signalling, are akin to those of rail transport, there is a distinct variation in the control of its vehicles for two distinct reasons: the great variety of routes which they can use, and the use of single vehicles, including tractors hauling freight vehicles.

The single vehicle of a road service has not only the great advantage of higher mobility, but has a much greater proportion of variable costs than a railway train, and the operator can more quickly and more largely cut his costs to meet a lessened demand, particularly on the freight side. On the other hand, for a regular long distance traffic, a series of lorries carrying 1 000 tons is at an economic disadvantage compared with his competitor (or should I say partner) on the railway line, but both have similar problems in regard to transhipment and distribution. For road passenger traffic the position is different because, in large degree, the omnibus runs to a scheduled service at specified times, but there is more scope for relief buses to meet extra demands or for reduced services to meet reduced demands. The difference between good and bad scheduling can cause the whole difference between an efficient and an inefficient undertaking.

But, despite these differences, the art of road traffic control is very like in nature to that of train control and the fundamental problems of the two differ in detail only. London transport, with its buses, trams and trolley buses, and trains has three distinct passenger movements each with its distinct features, but there is little *directed* through traffic between them, that being left to the whims or preferences of the London public and the many visitors to that tourist centre.

The maintenance problems of the road transport engineers do not differ fundamentally from those of the railway engineers who themselves have a fleet of 12 000 road motor vehicles in their care which are, however, mostly employed on short distance work and include a large proportion of « mechanical horses ».

I think I have said enough to indicate the

types of the controls of efficiency, perhaps oversimplifying the descriptions, and I have merely taken a few major examples, mainly based on railway experience in more normal times than the present. But whether for railways, road services, steamships, canals, docks or any other form of transport, the basic principles are the same :

(1) Cost each process and each part of it, not necessarily all the time and not necessarily in terms of sterling, and use the results as a tool of management,

(2) « Budget » expenditure and watch its actual course.

(3) Try any new device which appears worth it and scrap the old one relentlessly where it pays to do so.

(4) Standardise parts.

(5) Continually analyse blocks of all expenditure for one purpose, regardless of departmental boundaries and the way it is charged, and see whether, with a fresh mind, it can be reduced. The all-in cost of providing and running locomotives is an example.

[621 .33]

Electric traction using single phase 50 cycle current.

(Revue Générale des Chemins de fer, February 1948.)

The Congress of the French Association for the Advancement of Science during its last Session at Biarritz, in September 1947, heard two very important papers, one by M. PROT *and the other by* M. ARMAND *on what can now be expected from the use of single phase 50 cycle current for traction purposes in the electrification of the French railways. We are fortunately able to put before our readers the text of these two papers, revised and completed by their authors, and to follow them up with the summaries prepared by* M. ARMAND. *The* Revue Générale des Chemins de fer *will shortly be publishing a study on single phase 50 cycle locomotives which the French National Railways are shortly going to try out.*

I. General considerations,

by MARCEL PROT,

Ingénieur en Chef des Ponts et Chaussées,
Ingénieur en Chef des Transports au Ministère des Travaux Publics de France.

Today everyone is aware of the very serious coal crisis from which France has been suffering in recent years; this crisis is very serious because it affects not only France but the whole of Western Europe, and because it is the result of a general social evolution which was merely speeded up by the war and, it must be said, because the steps taken to remedy it so far have been ineffectual and uncertain.

Very great efforts are now being made in all branches of French industry to reduce wherever possible the normal consumption of coal, so as to make sure that there will be sufficient for those cases where it is absolutely essential. Now in France the railways use about 9 000 000 tons of coal, i.e. approximately 20 % of the national production, the greater part of this percentage — be it noted — of the high grade coals for which several important industries are fiercely competing. In principle the railway could assure its traction requirements by using other sources of power than coal — such as petroleum products or electricity — so that it was only to be expected that it should be asked to switch over to these alternative sources in order to economise the former; the Ministry of Industrial Production has made many strong representations to the Ministry of Public Works and Transport on these lines.

The development of the use of petrol and fuel oils is limited by the fact that these products are imported, and by the extremely high cost of diesel locomotives which can only be used on lines where there is sufficient traffic to assure a reasonable amortisation.

The development of electric traction on the other hand appears to be of value from several points of view :

1) *Output.* — The steam engine, subject as it is to conditions of weight and

size, is relatively less efficient than up-to-date plant [1 kgr. (2.204 lbs.) of high grade coal instead of 0.4 kgr. (14.11 ounces) of lower grade coal]. Even if electric current generated by steam is used, the saving in fuel is of the order of 55 % compared with the consumption of the most recent locomotives. If the source of the current is hydraulic, it is sufficient to use 1 ton of coal for the necessary consumption to make an *annual* saving of 1.5 t.

2) *Operating staff.* — The total saving in staff resulting from the change over from steam traction to electric traction is about 30 to 40 %. This saving is due to the fact that the output of the staff is appreciably increased, and a further increase is to be looked for when the use of certain safety devices becomes general in the future. Furthermore, electric traction, by doing away with the handling of fuel and simplifying the maintenance of locomotives, also reduces the amount of clerical staff required. It is worth pointing out that the change-over from steam to electric traction, even when this is gradual, will release trained staff (drivers, firemen, boiler-makers) whose skill, invaluable in the modern state, will be used with profit by many of the key industries, such as mining, steel or mechanical construction.

3) *The social point of view.* — Electric traction does away with the arduous work of firemen, shed and shop labourers; moreover the suppression of smoke is of great advantage to passengers and train staff, as well meaning cleaner stations, shops and houses near the railway.

4) *Production of current.* — The aforementioned considerations would remain of little value if the national production of electrical energy was insufficient; now from this point of view the situation appears to be very favourable. The consumption of the French railways was about one milliard kW-h. in 1939 compared with a total production of about 20 milliard kW-h., i.e. about 5 % which is relatively little. The electric supply programmes which will about double the production of current in the years to come will therefore enable the railway to double its consumption without altering its relative value.

It may be said that in France everything is in favour of the policy of electrifying the railway : the need for improving the power balance sheet, the possibility of using hydraulic sources of supply, the value of freeing skilled labour, and finally for a country who wishes to increase its tourist traffic, the fact that journeys will be made more agreeable, the trains cleaner, and the railway installations more up to date.

To these considerations we will add an argument of another kind, but one which carries great weight : if in certain industrial fields, the production of France does not come up to that of certain foreign products, there is no doubt that the construction of electrical equipment in France is in the « international » class. The electrification of the French railways can therefore be carried out on altogether modern lines, which in addition will also enable our specialists to take part in equipping the railways of other countries.

However valuable the advantages we have enumerated above, it will be noted that as far as the railway itself is concerned, they only affect the operating budget. On the other hand, it is well known that electrification involves heavy capital expenditure. Under present circumstances, the equipment of new lines could only be considered by the S.N.C.F. if such expenditure were considerably reduced. It might be agreed even if no benefits were obtained from the operation in view of the fact that the national interest makes it essential that every possible saving in the use of coal be made, but it should at least pay for the investments required.

From the point of view of the returns, it is necessary to make a distinction between the capital investment on motive power and that on fixed equipment.

The electric locomotive costs about twice as much as a steam locomotive, but taking the annual mileage, it will perform the work of two steam locomotives. It therefore makes no difference whether the S.N.C.F. invests its money in one or the other so long as the amortisation limit for the steam stock is not exceeded. Outside this limit it is still possible to balance the cost price of the electric locomotives by savings made in the operation through the use of electricity, since the expenses are roughly proportional to the traffic.

It is different however in the case of the fixed equipment where the cost instead of being proportional to the traffic varies according to the mileage and must all be charged to the electrification. The result is that in the case of each line there is *a fixed point at which it becomes a paying proposition,* determined by the number of services per kilometre and the importance of the track equipment.

In France it reaches a very high figure because the fixed equipment is very expensive. The current used (1 500 V. direct current) owing to the intensity involved makes it necessary to have every 15 or 25 km. (9 or 15 miles) feeding points for the overhead wires, which have to be real little power stations in which the industrial current (60 or 90 000 V. three phase) is transformed into direct current. Moreover as the intensity is very great, large and consequently heavy overhead wire lines have had to be used and consequently many poles have to be used.

When the work on the main line from Paris to Lyons has been completed only 10 % of the lines and 13 % of the permanent way of the S.N.C.F. will have been electrified, whereas to meet the fuel economy programme of the Government the proportion should be 30 to 40 %. This shows how much remains to be done in the way of providing equipment. But it must also be remembered that a large number of secondary lines will be affected, as the more electrification is proceeded with, the more one is led by operating requirements no longer to limit the problem to the main lines but to look upon it as a whole system in which all the lines are linked up together. The same conclusions also result from the fact that the light steam locomotives belong to older types than the heavy locomotives. If only the lines with heavy traffic are to be electrified, we will have excellent locomotives to spare which it will be hard to use elsewhere, so that we shall still have to face the cost of bringing the stock of light locomotives up to date. Finally there can be no question of prematurely altering the new steam locomotives which the S.N.C.F. has acquired since the liberation, the amortisation of which will extend over some forty years.

It is obvious however that an electrification programme which includes a large number of secondary lines comes up against the snag of the possible returns mentioned above. In fact if 1 500 V. direct current is to be used recent calculations confirm the conclusions adopted by the Higher Railway Council in 1923 that *only a few hundred kilometres of lines* should be electrified in addition to the Paris-Lyons line.

The problem is therefore as follows :

Are there any systems of electrification in which the cost of the fixed equipment will be much less than with 1 500 V. and is it possible to make use of two different systems on one and the same railway?

The Italian railways have adopted 3 000 V. direct current with which the cost of the fixed equipment is less than ours, but here again the cost price is too high. Alternating 16 $^{2}/_{3}$ period current

has given good results in Switzerland, Germany and Sweden as, since the current is transformed on the locomotive itself, the overhead wires can be under very high tension (15 000 V. for example) which considerably decreases the intensity. This system has the double advantage therefore of making it possible to use small and therefore light contact lines, and to space the substations some 50 km. (31 miles) apart. On the other hand, it has the drawback of necessitating special current for traction purposes.

The most attractive solution from many aspects would appear to be feeding the locomotives direct with industrial single phase 50 period current at high tension.

Immediately after the liberation, M. ARMAND, who is now Deputy General Manager of the S.N.C.F., decided in favour of this solution and has been its ardent partisan ever since; his faith has not been shared by everyone however and many technical experts were of the opinion that experiments already made condemned such a solution irretriveably.

M. ARMAND put some technical experts on the job who soon proved their broadmindedness and were not afraid of future judgments. We have here a good example of technical collaboration with M. DE GIACOMONI, the engineer of a French electro-mechanical constructional firm, and MM. GARREAU and NOUVION, Head Engineer and First Engineer of the S.N.C.F., Electric Traction Research Department, conscientiously investigating the problem with the assistance of a remarkable group of specialists and making experiments on the high tension line set up by the Germans in the Höllental Valley in the Black Forest (1).

After two years arduous work, the investigations and experiments made justified the highest hopes and the most sceptical were converted.

The savings obtained by this method compared with direct 1 500 V. current, savings of the order of 50 % in the case of fixed equipment, make it possible to consider so equipping lines with considerably less traffic and the formation of completely electrified systems, covering not only the main lines but all the branch lines.

The figure on page 434 makes it possible to compare the fixed equipment required with various types of equipment in the case of a given line.

If, as we think, the next few months see the realisation of these hopes, this will be a great French achievement and the proof that technical progress is a safe bid when a definite problem is set and its solution resolutely sought.

(1) When the S.N.C.F. undertook trials on the Höllental line certain German technicians, such as Professor Müller and Dr. Kilbe were already in favour of 50 period current, although the Reichsbahn had decided that the results of the trials were negative.

II. Technical problems arising in connection with the use of 50 cycles per second single phase current for traction purposes and their solution,

by M. ARMAND,

Deputy General Manager of the French National Railway Company.

The application of 50 cycles per second single phase current to traction purposes, whilst offering attractive possibilities as regards the extension of electric traction in France, raises certain technical problems.

We propose to review these problems briefly and to indicate how they can be solved.

First of all, let us consider the difficulties met in feeding power to motor stock. The feed from the high tension system is through much simplified substations containing nothing but the transformers feeding the overhead contact wire. If the voltage on these wires be 20 to 25 kV., the distance between substations may approach 100 km. (62 miles), so that, in practice, they can be located where the existing H.T. lines or posts best lend themselves to their installation.

The first difficulty is that when single phase current is taken from the three phase system, the phases become unbalanced between phases and this results in variation in voltage in loads and in phases, which can result in annoying perturbations if the unbalance be large. This latter has the effect on lighting installations of shortening the life of the lamps or of reducing the lighting efficiency according as they are « over-volted » or « under-volted ». Moreover, in rotary machinery connected to the mains this sets up in them parasitical fields generating inverse currents producing braking effects and supplementary losses.

These drawbacks can be avoided if certain precautions are taken.

First of all, steps must be taken to reduce the amount of disequilibrium by dividing the contact line into independent sections fed by different phases.

Then, and usually adequately, the disturbing effects are lessened by careful selection of the points of H.T. feed. The important thing is to be coupled to the points of the distribution system and feed through lines of lower impedance to the rotaries which are suited to the absorption of parasitic currents (compensators of large posts, alternators of power stations equipped with dampers, etc.).

Usually, this requirement is best met by connecting up to large centres or to transmission lines at very high voltage.

Then, if considered necessary, balancing devices can be installed in the substation as, for example, in place of ordinary transformers, transformers of the Scott type which will ensure a better division over the three phase of the single phase loads when sections of lines with similar loads are fed by their two secondary windings.

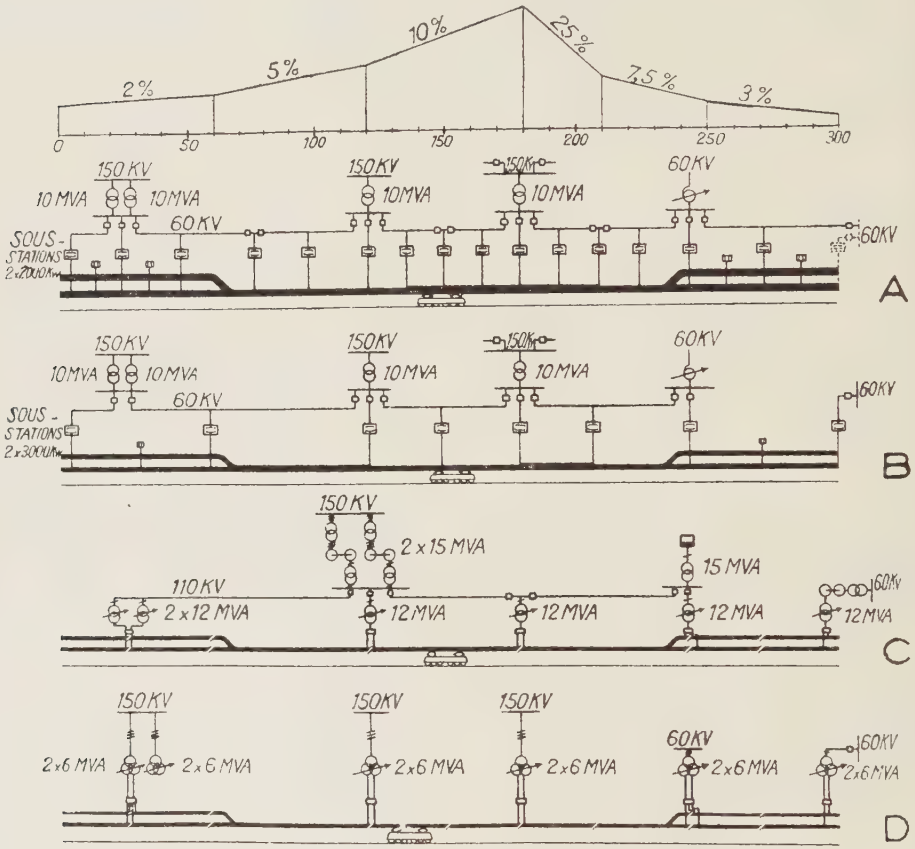
It should be noted that the results of investigations and trials and, in particular, of those made by the S.N.C.F. in the Baden region, permit us to say that the interconnection of the French grid is such that single phase traction current can be supplied without dangerous disequilibrium.

Another objection concerns the fixed installation. With 50 cycle alternating

DIAGRAM SHOWING THE ELECTRIFICATION OF A LINE WITH MODERATE TRAFFIC

intended to show the importance of the fixed equipment according to the type of electrification.

(Clermont-Ferrand-Nîmes : 300 km. [186.412 miles], 120 km. [74.565 miles] being double track.)



A. Using 1 500 V. D.C. (French system) the railway has to erect :

— a high tension electric line alongside the track (60 000 V. three phase industrial current) ;

— 15 substations, i.e. plant to transform the alternating current into direct current;

— heavy copper overhead wires, as the current intensity is high (2 000 amperes).

B. Using 3 000 V. D.C. (modernisation of 1 500 V. system developed in particular in Italy) :

— the same high tension line alongside the track, but as the intensity is lower, fewer substations are required (8 only) and the overhead wires are lighter.

C. Using single phase 15 000 V. 16 2/3 periods (Swiss, Swedish and German types) :

— the tension is high (15 000 V.), the intensity low, so the overhead wires and their supports need only be light, but it is still necessary to have a high tension line alongside the track (110 000 V.) for the special 16 2/3 current which has to be produced in three power stations (from industrial current) and transformed to the tension of the overhead wires in 5 substations.

D. Using single phase 20 000 V. 50 periods current :

— with the tension of 20 000 V. now possible, the fixed equipment is reduced to the minimum and merely consists of a very light overhead wire, fed by simple transformers placed near the lines and transmission lines from the general system (5 substations).

track current serious disturbances in the telecommunication lines along the track were to be feared. This question was solved by the fact that the Post Office has a general programme for replacing overhead wires by cable laid along the roads. This left no such problem to solve.

Now let us see what happens to the motor rolling stock.

We are now dealing with the essential problem resulting from the difficulty of providing good 50 cycle single phase traction motors.

Let us glance at the design of traction motors.

Whether single phase or direct current, the type of motor used everywhere is the series motor with collector.

The self-regulating form of its power-speed curve is exactly what is wanted for traction purposes. For an increase in speed, there is a corresponding reduction of couple, and vice-versa. The speed adapts itself automatically to the load. It is robust and able to stand heavy overloading.

Compared with direct current motors the single phase motors with collectors have certain important differences, both as regards construction and functioning.

The voltage allowable across the commutator segments of the collector is lower than with direct current so that, for equal diameters, the single phase motor is the less powerful.

With alternating current the inductor reduces the specific power. It can be neutralised in the case of the rotor by adequately compensating the motor. As regards the stator, it can be reduced by lessening the importance of the poles. Moreover, in the case of single phase motors, the fluxes are feeble and the relative importance of the rotor to the stator is greater than with direct current motors.

The main difficulty to overcome is that of the commutation.

With direct current the problem is relatively simple. The inversion of the direction of the current imposed on the turn which commutates, induces in this turn a *dynamic* electromotive force, the harmful effects of which on the commutation are proportional to the speed and to the principal current. It is remedied by auxiliary commutating poles which produce a reversed electromotive force annulling the former.

With alternating current, the same phenomenon is found, but it is pulsating and there is an additional one due to the principal alternating flux which induces in the commutating turn a secondary electromotive force which we can call *static*, similar to that which develops in the secondary winding for transformers. This static electromotive force is proportional both to the frequency and to the intensity of the flux, i.e., to the current.

The voltage between segments will be the resultant of the two electromotive forces — one dynamic, the other static. These two electromotive forces are in quadrature. Both depend upon the current and one is also a function of the speed. The resultant consequently will be out of step with the current by an angle varying with the speed. As in the case of direct current, it can be destroyed by means of auxiliary poles provided the flux for these auxiliary poles is dephased by the necessary amount relatively to the current. This is achieved by inserting a suitable resistance in parallel with them. For perfect commutation the value of the resistance should be varied to suit each feed which, in practice, cannot be arranged. An average value suitable to the most usual running conditions has to be accepted.

It is appreciated that the wider the departure from this running condition the higher the tension between windings becomes and the less satisfactory the commutation. Speeds cannot be maintained for a long time very different

either above or below that for which the resistances were set. In particular, when starting, the acceleration should be high so as to reach quickly the region of speeds corresponding to good commutation.

With single phase tractions the limits of the permanent running speed zone does not depend solely on the heating characteristic of the motor, (thermal limitation), as in the case of direct current, but also on the commutation voltage which should not exceed a certain value, (commutation limitation).

To-day, thanks to the constant progress in the manufacture of single phase traction motors, the commutation problem for $16\,^2/_3$ cycles is considered as solved. In the case of 50 cycles the commutation phenomena are of the same kind but become more serious. The fact of multiplying the frequency by three increases the static electromotive force which, as we have seen, is proportional thereto to the same extent. It is necessary to bring down the electromotive force to its permissible limiting value, that is, to reduce the polar flux in proportion.

The result is that the constructional features of the motors are totally different in the case of 50 cycle current.

The need to reduce the polar flux involved reducing the rotor voltage to a third and this in turn means for equal power a current three times greater which, in turn, increases proportionately the collector. To get the same torque the number of poles has to be increased three times, the number of brush lines, too, has to be tripled.

The result is a motor appreciably heavier than that of $16\,^2/_3$ cycles and of more delicate construction. The development has been the object of intensive research from which most favourable results have now resulted.

We must not forget, owing to the inherent difficulties of the single phase motors, the special advantages it possesses.

With direct current the motor has to be designed for the maximum line voltage although its operating voltage is appreciably lower. Then, too, as the voltage cannot be regulated, starting involves the use of resistances which cannot be kept in circuit for more than a limited time, and it is necessary to vary the excitation to get for each coupling a sufficient range of speed. At high speeds, in particular, the power can only be increased by weakening the excitation. The possibilities of this method of regulation are to a certain extent limited as the electrical equipment required to eliminate the resistances and reduce the excitation involves great complication and is one of the most striking features of the direct current locomotive.

On the contrary with the series alternating current motor perfectly progressive regulation with the speeds can be obtained very simply by the continuous variation of the voltage between zero and the maximum value, thanks to tappings taken off the transformer and to its being possible to let the conductor remain indefinitely on each notch. The result is that this motor can be designed to give its full power even at high speeds and can be used all the time to its limit.

* * *

Having reviewed these general considerations, let us now indicate the practical solutions put forward to produce 50 cycle single phase locomotives.

Two classes of locomotives are in being : the first, locomotives in which the single phase current is directly used by the collector type traction motors, the second, locomotives on which the single phase current is first of all transformed by a transformer group.

A locomotive of the first class is in use on the Höllental line in Baden, equipped in 1936. Two locomotives of the same class are under design for the S.N.C.F. One of these two locomotives has a motor for each axle. The other a double motor per axle which simplified the design. Each develops about 550 H.P. per axle.

These locomotives with direct feed motors provide the simplest solution.

The second class of locomotives on which the current is converted can be based on a number of designs. The existing types are :

— Kando system, in use on the Budapest to Hegyeshalom line, in which the single phase current is directly transformed by a rotary set taking three phase current which feeds the traction motors of the revolving field type;

— a Krupp locomotive with converter group based on somewhat the same principles and in use on the Höllental line;

— two locomotives in service on the Höllental line, in which the single phase current is converted into pseudo-direct current by mercury rectifiers.

The S.N.C.F. has designed a locomotive with a rotary single phase direct current set. The 50 cycle single phase current after having the voltage reduced by a transformer feeds an asynchrone motor which drives the direct current generators. The traction motors are ordinary D.C. motors but fed at variable voltage, that is to say, by a single regulation of the voltage. In spite of the double transformation of energy, the weight of the locomotive is no greater than that of the locomotives with directly fed motors.

For the present, the S.N.C.F. is devoting itself to the design of these three types of locomotives (two with directly fed motors and one with rotary converter). The locomotives with rectifiers none the less may be found to be sufficiently interesting to follow up in view of the developments in mercury arc rectifiers under the new forms in which it is now beginning to be built.

* * *

The foregoing is a review, and far from complete, of the technical problems that have been investigated. In this short article it has been possible briefly to enumerate the main questions and show in general lines the results obtained. Finally, a particular point deserves to be noted — the need, at least in the case of a number of locomotives of the pool, to be able to operate single phase locomotives in terminal stations of the 1 500 volts direct current lines. These stations will be « single current » stations to avoid difficulties due to contact lines of two kinds of current. A number of single phase locomotives must, therefore, be able to operate, even at reduced speed, under 1 500 volts direct current overhead lines. This problem has been dealt with in the case of the three prototypes mentioned. The locomotive with rotary converter provides a very simple, perfect solution of this point. With the two single phase locomotives with direct feed, the design includes an auxiliary set, either direct-direct or direct-single phase of 30 cycles of reduced power.

III. Conclusions,

by M. ARMAND.

Electrification using industrial frequency current is the most natural and has been the object of technicians from the start.

Two main factors prevented this type of electrification being carried out : one, the difficulty of designing suitable locomotives, the other the impossibility, until the main supply systems were developed on a large enough scale to draw the energy required by the railways with sufficient reliability for operating purposes and without pulling the main supply system out of balance. This second reason explains why, in the first electrification, the railways had to build their own power stations and distribution lines and this also explains why, in some countries, it had not hesitated to adopt a special current such as that at $16\,^2/_3$ cycles.

To-day, both these obstacles have disappeared. The progress in traction with alternating current (direct feed motors, rectifiers, rotary sets) is such that locomotives can now be built to operate on industrial current.

In a country so well equipped with electric transmission systems as France the railways have no need to build their own special transmission lines, as they can take current from the National high tension lines, and so avoid any duplication.

To-day, therefore, electrification using industrial current can be undertaken, which will be characterised by :

1) the suppression of all special railway high voltage lines;

2) the supply of current to the overhead wires by simple transformers spaced 50 to 100 km. (31 to 62 miles) apart;

3) a high supply voltage — 25 000 volts, for example — and consequently a light overhead wire.

We believe we can say that the cost of the fixed installation will cost less than half that for 1 500 V. and the saving in material will be even greater. The installation being much simpler, the work can be done by the railways themselves. From this fact, electrification schemes will cease to have the character of major capital works they have had so far and will become part of the general programme for the improvement of the railways.

The single phase locomotives should, ultimately, cost the same as the 1 500 volt locomotives : the bi-current locomotives being slightly more costly. This difference could only reduce the saving in fixed installations at most from 55 to 45 %.

Including the locomotives, the saving in material for a line that has been investigated are 45 % of steel, 45 % of cement and 65 % of copper that would have been needed.

There is therefore a great reduction in the investment in materials and money to be expected from the new method of electrification, which will enable us to profit from all recent progress in technical matters.

[385 .064 (44)]

« Door-to-Door » Exhibition, French National Railways.

An interesting display of containers and other material designed to obviate rail-road transhipment.

(From The Railway Gazette, December 10, 1948.)

M. Marcel Flouret, President of the French National Railways Administration, opened the « Door-to-Door» Exhibition at the Gare des Batignolles, Paris, on October 11. The exhibition remained open from 2 p.m. to 6 p.m. daily until October 16 inclusive. The exhibits were of special interest to manufacturers and business men who use containers for rail, sea, and air transport.

Tractor with flange-wheel trailer on rails on flat wagon.

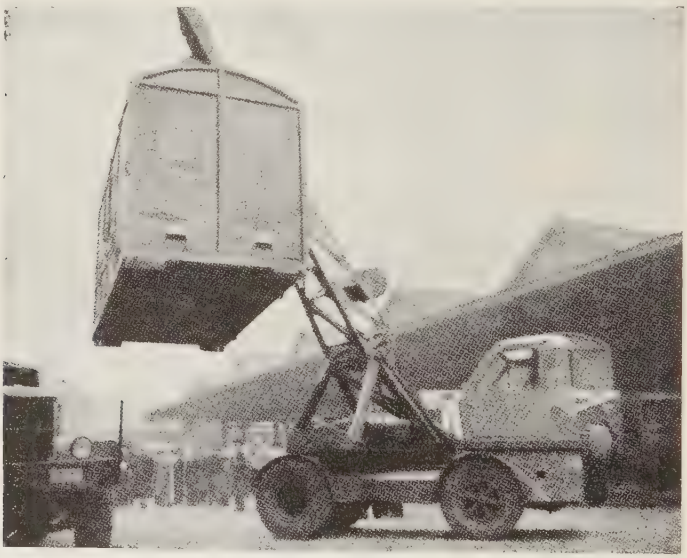
Door-to-door delivery by the S.N.C.F. and associated road hauliers under satisfactory conditions of speed and safety was exemplified in the material shown. Advantages claimed included a reduction of intermediate handling and transhipment of goods, thus saving constantly increasing labour costs.

The S.N.C.F. showed ten different types of containers, including three small mobile containers running on small swivel wheels, of a capacity from one to three cu. m., and seven large containers with capacities of from 3-6 to 18 cu. m. Private firms exhibited small containers made of light alloys, one fitted as a refrigerator, and larger types for transport of cement, sheet steel, and household furniture.

Containers as trailers.

One of the most interesting exhibits was the trailer and tractor used for rail and road transport of the Groupement Technique des Transporteurs Mixtes (G.T.T.M.). The trailer is a roomy van of 24 cu. met. capacity. Great success is claimed for this method of solving the problem of rapid long-distance

transport from door to door. It is known as the U.F.R. system, promoted by the Union des Transports Ferroviaires et Routiers in collaboration with the S.N.C.F. Road tractors of normal type are used, but the trailers and the railway flat wagons on which they are loaded are built specially for railway use. The S.N.C.F. places such wagons at the disposal of hauliers, who own the U.F.R. trailers and tractors. Financial arrangements are made to enable road hauliers to acquire the trailers on easy terms.



Griffet 5-ton crane lifting container.

The trailer is fitted with flanged wheels and the flat wagon has two rails to receive it. When run on to the wagon by the aid of guide rails the trailer is held firmly in position by clamps gripping the flanges and acting as shock absorbers. Two men only are required, one to drive the tractor and the other to fix or unfix the clamps. A three-ton trailer may be loaded in less than two minutes, and the tractor is then ready to bring up another trailer. The flanged wheels of the rear axle of the trailer are concentric with its two road wheels. A string of wagons also may be loaded; the rail gap between any two wagons is filled by hinged lift rails to make the track continuous. Oil tanks, similarly fitted with flanged wheels, also may be transported as trailers. Tractor and trailer have instantaneous automatic coupling.

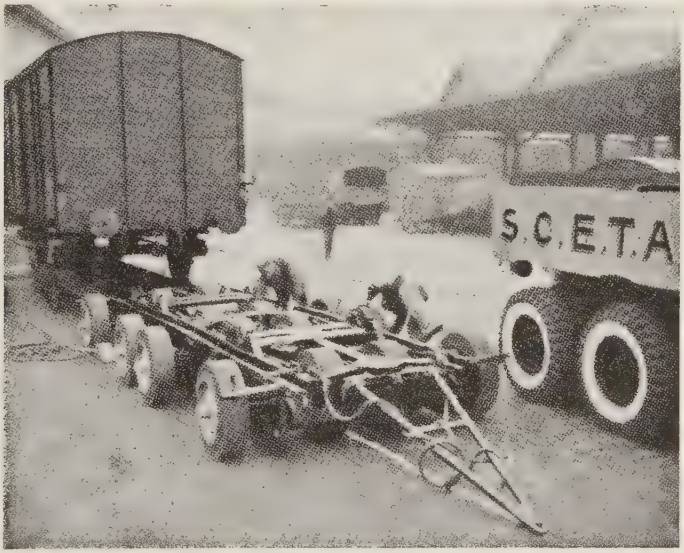
Forty goods stations in France are equipped for the U. F. R. system. There are 400 trailers in use, and upwards of 300 in course of construction. The Monnet Plan for French reconstruction and equipment estimates that a total of 1 960 trailers will be available in 1950.

Another form of container (trailer) and tractor forming together a four-wheel vehicle to run on the road was exhibited by the Somcort firm. This container stands on its own four feet when the trailer is detached To allow this, its road wheels are raised and

remain suspended under the container, and do not act as bearer wheels. Mechanism attached to the trailer and actuated by a hydraulic jack lifts or lowers the wheels. The same applies to two small bearer wheels at the rear of the tractor. Coupling is automatic. Five such two-ton trailers are loaded side by side crosswise on a single 15-ton flat wagon, from any side platform and thus five containers with ten tons of goods are quickly ready for despatching.

The Huet-Fives-Lille firm showed its trailer, fitted with removable wheels, for small containers. Another interesting exhibit was the rubber-tyred road trailer for carrying railway wagons to factories, warehouses and other premises having no adjacent railway sidings.

Portable cranes for loading and unloading containers on to flat or open railway wagons were also on view, with other apparatus for lifting containers. The 5-ton Griffet crane, capable of travelling under its own power at a speed of 15 m.p.h., has a clearance of 19 1/2 ft. under the hook of the pulley block. The crane was exhibited at work lifting 5-ton containers into open wagons with high sides.



Rubber-tyre road trailer for carrying railway wagons.

[625 .17 (73)]

Power gaging machine,

Something new for large rail-laying gangs.

(From *The Railway Engineering and Maintenance, November 1948.*)

To improve the quality of work performed by the man-power available, the Western region of the Pennsylvania has developed two power gaging machines for use in conjunction with the rail-laying operations carried out with its rail-train organizations. These machines, which provide for six-point gaging of each rail length, are each powered and moved by a 500-cu. ft. on-track, self-propelled air compressor, which also supplies air for driving the gaging spikes.

General set-up.

The power gaging machine is essentially a specially equipped and operated low-wheel carriage, 38 ft. long, which provides for pushing the new rail inward or outward to gage throughout its length by means of a series of air-operated gage rods and clamps, and which carries on several movable platforms the entire force of men involved in gage-spiking operations, including those distributing spikes, setting spikes with hand hammers and driving the spikes with pneumatic hammers.

Supplementing this unit, which is moved forward progressively, one rail length at a time, by the air compressor, is a second air compressor outfit, of 315 cu. ft. capacity, with from three to five pneumatic spiking hammers, which does all fill-in rail spiking and drives certain plate-holding spikes.

The power gager, which is operated as one continuous unit throughout its 38 ft. of length, is essentially two car units, closely coupled together, each mounted on two pairs of motor-car type wheels spaced 14 ft. 3 in. apart—with a wheel spacing of 7 ft. 9 in. at the center of the coupled units.

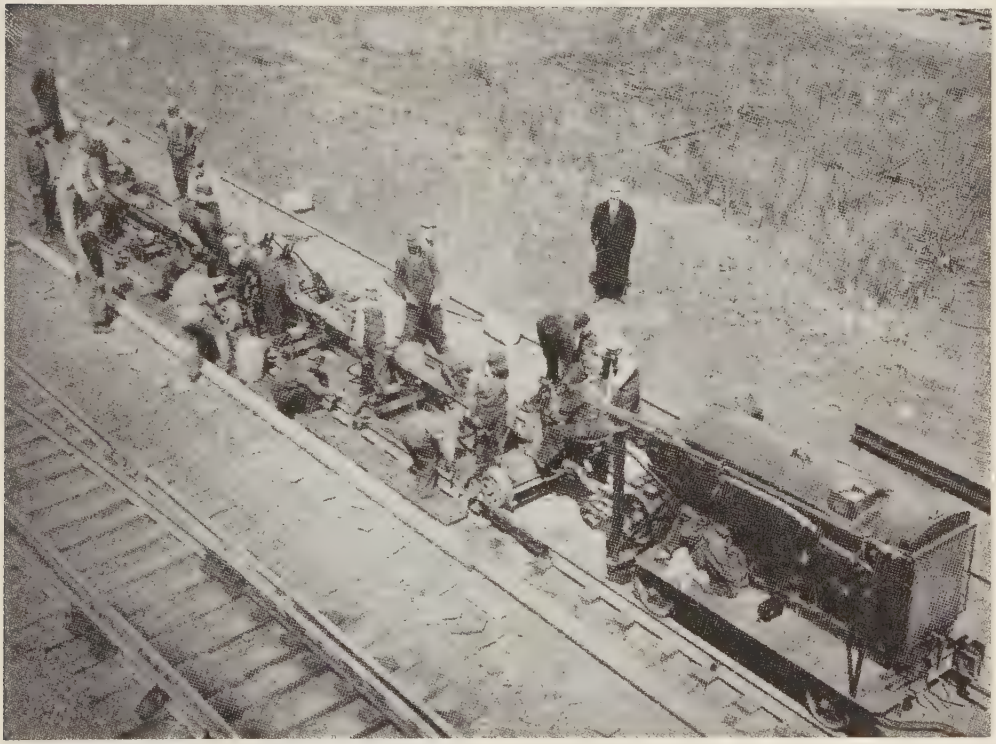
The frame.

The frame of the gager, as a whole, consists essentially of a heavy T-section member, continuous except for a short gap at the center, which is mounted base up and approximately 18 in. above the top of rail. This frame, or center sill, carries all of the units of the machine, including six combination power gage rods and clamps (two between each pair of wheels); four vertically raising and lowering platforms (two, in line with each other, along the outer side of each track rail); a total of 22 air cylinders of different sizes for the operation of the gage rods, gage clamps and platforms; and all air piping for these units, as well as for the operation of the pneumatic spike drivers. In the main, all of the air piping is carried along and fixed to the sides of the gager center sill, twin outlet valves for the spike drivers being provided at uniform intervals throughout the length of the unit on top of the sill—two between each set of wheels.

The two working platforms on each side of the gager, which are continuous except for the break at the center coupling, each consists of a single 2-in. by 12 in. yellow pine plank, framed along both sides for stiffness by light structural steel channels. The platforms are attached to transverse crossheads at right angles to the main center sill, which, in turn, have direct connections with air cylinders above, by means of which they and platforms can be raised and lowered. Thus, all four sections of platforms are raised and lowered simultaneously. The raise, being designed to be only sufficient to clear road crossing, switches, etc., when it is desired to move the unit forward, is about 10 in. In

their lowered position the platforms come to rest on the tops of the ties, from which position all spiking is done. Operation of the platforms is controlled by an operator at the rear of the unit as a whole, who, from a raised seat where he can observe all operations, also operates the power gage rods and clamps and synchronizes the work as a whole.

is to be moved forward, the rods, under the control of the operator, can be retracted until their opposite ends clear the gage sides of the opposite rails. Simultaneously, the clamps, which contact the outside of the rail at about the center of the web, are drawn outward and upward from the rail, entirely in the clear. When the machine has been



Looking down on the power machine—gaging six points in each rail length at one time.

The gaging assemblies.

The six power gaging assemblies, which are spaced about equally along the length of the unit, include six power gage rods and six power rail clamps. Each of the gage rods, which are 1 in. in diameter, is retractable in length through a knuckle joint at the center, so that when the gaging machine moved forward to a new gaging position and brought to a stop, the gage rods are moved outward to true gage length between opposite rails, forcing the new rail out, if necessary, while the clamps are lowered, forcing the rail inward to tight contact against the ends of the gage rods.

On high-speed tangent, the track is gaged

to 4 ft. 8 1/4 in., the recently adopted standard gage for high-speed tangent track on the Pennsylvania, and the gage rods are normally set to this measurement. However, by the addition of shims back of the hardfaced contact tips, the rods can be increased in

The gager in action, spiking, with platforms lowered on ties.

length as desired, and new tips can be substituted when necessary to compensate for wear of the tip.

As only one line of track rails is relaid at a time in the rail-laying operations, the platforms on the new-rail side carry the entire gaging force, together with supplies of spikes and the pneumatic spike drivers. The force involved includes five men with the pneumatic spike drivers, spaced at about equal intervals along the length of the gager (two within each of the 14-ft. 3-in. wheel spacings, and one between the wheels spaced 7 ft. 9 in. apart); five more men, who set the spikes for the hammer men; and three helpers, who open spike kegs along the right-of-way, pile spikes on the gager platforms and center sill within easy reach of the spike setting men, and give such other assistance as may be necessary.

With each setting of the gaging machine over a new rail length, each of the power hammer men drives two spikes in each of two ties, leaving one tie unspiked between the two ties. Thus, ten well-spaced ties are fully gage-spiked with each setting of the machine, requiring the driving of 20 spikes. When this spiking has been completed, which usually requires from 50 to 60 sec., the gage operator blows a whistle, raises the spiking platforms, and signals the compressor operator to move ahead. In the next advance position, after again sounding the whistle the operator lowers the platforms to working position on the ties, and gage spiking operations are repeated.

Fill-in spiking.

In the fill-in spiking behind the power gager, a 315-cu. ft., trackmounted, self-propelled air compressor is used, with from three to five pneumatic spiking hammers —this outfit usually working from 100 to

Moving ahead, with the platforms elevated clear of the ties.

1 000 ft. behind the gager, depending upon the working conditions encountered. Three of the hammers are always used, one or two others being added as may be necessary to catch up with the gaging operations. Both this compressor and that used with the power

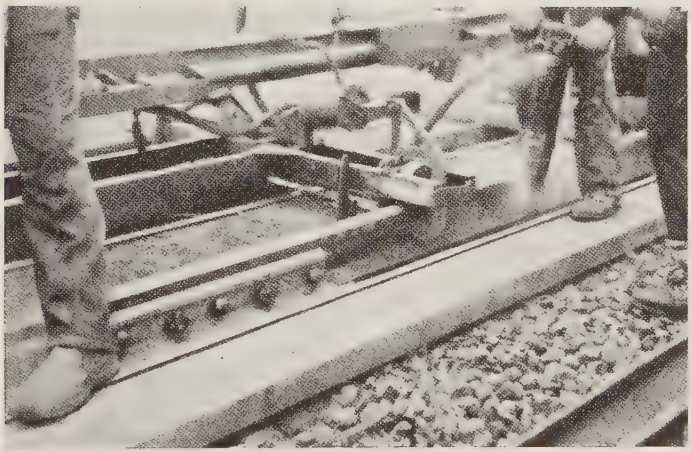
gager are propelled by air motors, this type of drive having been found better adapted to the frequent stopping and starting involved in the work.

Spiking first line of rails.

In the fill-in spiking of the first line of rails laid, two rail-holding spikes (one on each side of the rail) are driven in each of the ties not spiked in the gaging operation. In addition, one plate-holding spike (on the outer end of the plate) is driven in every tie—making, at this stage, three spikes in every tie.

When driving the fill-in spikes as the second line of rails is brought up, two rail-holding spikes are driven in each tie not spiked during the gaging operations, and, on the opposite rail, a second plate hold-down spike is driven in every tie (on the inner end of the plate). Thus, with the completion of the rail laying, the first line of rails laid has two rail-holding and two plate-holding spikes in each tie, while in the case of the second line of rails laid there are two rail-holding spikes in each tie. Placing the plate-holding spikes in the second line of rails is deferred, pending subsequent working of the track to give it a final line and surface, with such tie renewals as may be necessary. Completion of the delayed anchor spiking of the second line of rails is done during the winter months.

In connection with all of the fill-in and anchor spiking, the spike holes are pre-bored, using two or three self-contained, gasoline engine-driven wood boring machines—working between the power gaging and fill-in spiking operations. Furthermore, all spikes used in the fill-in and anchor spiking operations are hand set, with light hand hammers, by two or three men, as is required, each equipped with a Kershaw one-man spike-setting carriage.

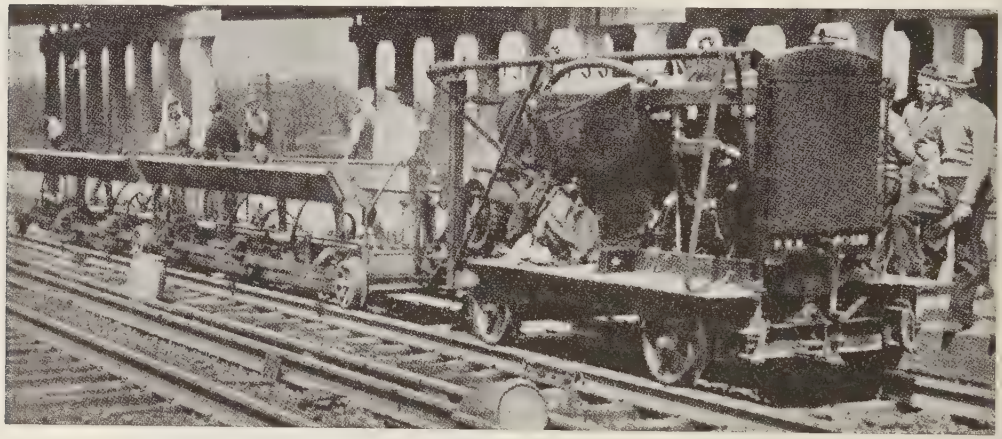


Close-up view showing gage rod, and outside clamp pressed against the web of the rail.

Clearing for traffic.

Since the gaging machine cannot be removed from the track readily to clear for traffic, it is hauled into the clear for trains and at the close of the day by its accompanying

self-propelled air compressor. During such moves of the machine, all of the platforms are elevated to their fully raised positions, and are then swung upward to positions directly over the body of the machine, where they are held securely by chain slings.



The power gaging machine, with platforms raised within clearance limits, ready to be hauled into the clear by the air compressor.

The power gager described is best adapted for gaging tangent track and relatively light curvature, which makes it particulary well suited to conditions found on the Western region. Where curvature is involved, and especially when heavy rail is being laid, use of the gager calls for the closest supervision to be certain that the rail is brought to true gage.

The power gaging machines being used on the Western region were designed by Pennsylvania employees at Fort Wayne, Ind., and were built in the road's shop at that point. They are operated under the general direction of C. G. Grove, chief engineer maintenance of way of the Western region.

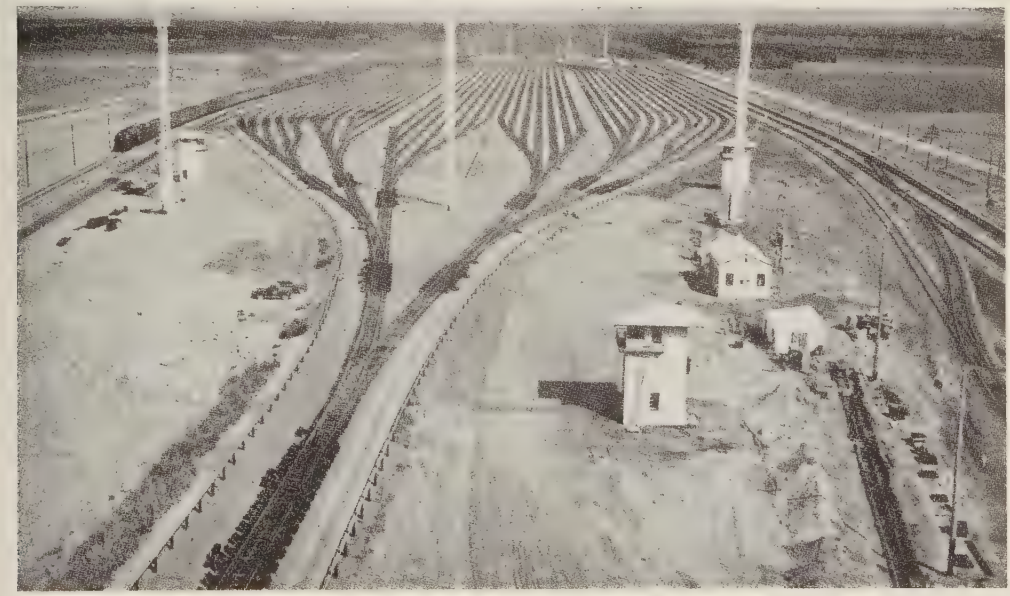
[656 .212 .5 (73)]

Builds second large retarder yard to improve operations.

(From the *Railway Age, October 30, 1948.*)

The second large modern retarder yard to be completed by the Union Pacific in the past year has been placed in service—this one at North Platte, Neb. Built at a cost of $3 500 000 the new yard is somewhat larger than a similar yard completed last fall at Pocatello, Idaho*. The North Platte yard follows the same general pattern as the earlier yard in its design and arrangement and the modern character of the facilities provided for expediting the classification of cars. These include teletypes for transmitting train consists, talk-back loud-speakers for communication between various points in the yard, and two-way radio systems that provide contact between the yardmasters and the crews of yard locomotives.

North Platte is 281 miles. west of Omaha, Neb., on the company's double-track main line. Previously, the yard facilities there consisted of 20 tracks on which cars were classified by a conventional flat-switching operation. The new yard is five miles in length over all and is divided into four major sections—a receiving yard, the incline, the classification yard and a departure yard. It is designed for classifying both eastward and westward traffic.

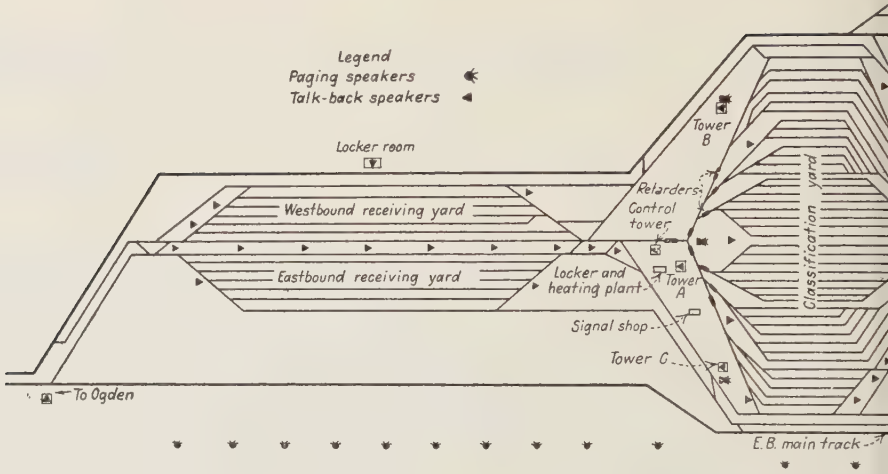


(All photographs courtesy of the Union Pacific)

The incline and classification yard as seen from the top of a 100-ft. light tower in the vicinity of the retarder yardmaster's office.

Construction of the new yard is in line with the road's policy of modernizing its facilities and of consolidating classification work at

* A détailed description of the yard at Pocatello appeared in *Railway Age* of January 10.



fewer terminals, reducing detention and permitting an increase in the average tons per train. With respect to eastward movements, the classification of traffic at North Platte for the Council Bluffs (Iowa) and Kansas City (Mo.) gateways, and further classifying of cars for delivery to connecting lines, results in reduced switching at the latter points and expediting deliveries to connecting roads.

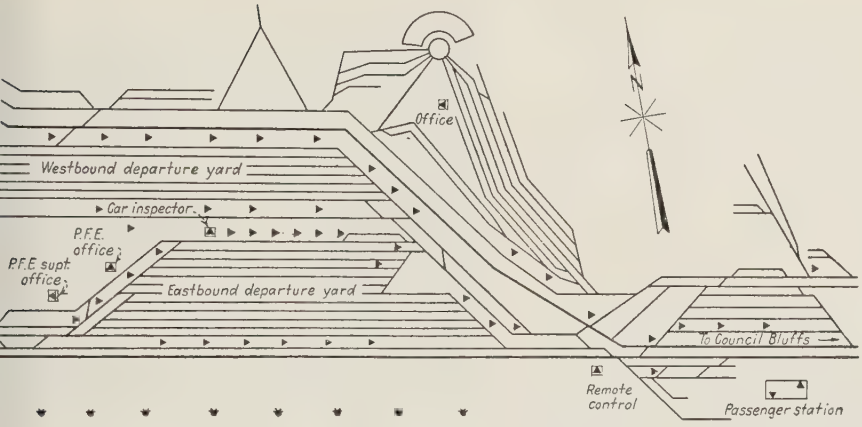
In handling westward traffic at North Platte separate classifications are made for Colorado, the Southwest, the West and the Northwest, thereby reducing the amount of switching required at other terminals.

In the new layout at North Platte the receiving yard, the incline, the classification yard and the departure yard are arranged in this order from west to east and are in line with each other. The eastward and westward main tracks skirt the south and north sides of the yard, respectively. The receiving yard has 12 parallel tracks having a maximum length of 6 262 ft. This yard is divided into two parts, one for eastbound and the other for westbound trains. The classification yard has 40 tracks ranging in capacity from 15 to 42 cars, and the departure yard has 16 tracks, also arranged in groups for eastward and westward traffic. The total capacity of the yard is 4 400 cars, including 1 400 for the receiving yard, 1 400 for the classification yard, and 1 600 for the departure yard.

Has group arrangement.

In the classification yard the main lead down the incline divides into two tracks, each of which serves as the lead for half of the yard which is symmetrical about the longitudinal center line. On each side of the center line the tracks are divided into three groups, with a separate lead for each group. The yard has nine car retarders of the electro-pneumatic type, one on the incline track, one each on the leads to the two halves of the yard, and one on the lead to each of the track groups.

On the approach to the classification yard the lead rises on a grade of two per cent to the crest and then declines on a grade of four per cent through the first retarder, the purpose of this latter grade being to accelerate the speed of the cars and obtain sufficient separation between them to permit operation of the switches. Through the retarder in the lead to each half of the yard the grade is 1.62 per cent, and the lead for each group is on a grade of 1.5 per cent, 1.64 per cent or 2.02 per cent, depending on the group. The body tracks of the classification yard have a descending grade of 0.2 per cent.



rammatic plan of the new North Platte yard, showing locations of the intercommunication and paging units

All switches in the classification yard are of the power-operated type. These switches and the retarders were furnished by the Union Switch & Signal Co. For controlling the switches and car retarders, three control towers are provided. At the crest of the incline is another tower housing the office of the retarder yardmaster. This office is on the second floor of the tower on the side next to the incline track and has windows on three sides to give the retarder yardmaster an unobstructed view of the receiving yard to his left, the classification yard to his right, and the cars moving over the crest in front of him. Eleven 100-ft. steel floodlight towers illuminate the incline and the classification and departure yards for night operation.

Other new buildings constructed as part of this project include an office for the general yardmaster which, topped by a multi-windowed tower, is located between the classification yard and the departure yard. This structure is 38 ft. by 122 ft. in plan, and at one end is adjoined by a locker room for trainmen, which is 24 ft. by 104 ft. in plan. Also there is a locker room for carmen (24 ft. by 84 ft.), a locker room for switchmen (20 ft. by 42 ft.), a store building (24 ft. by 100 ft.), a shop building (24 ft. by 64 ft.), and garage and compressor buildings. All are of brick and concrete construction and have asbestos shingle roofs.

Car inspection facilities.

As cars move up the approach to the crest from the receiving yard they pass a station where warm oil is injected into the journal boxes to assure the proper acceleration as the cars move down the incline. Beyond this point on the approach to the crest the cars pass a station where they are thoroughly inspected for defects. The structure for this purpose embodies an enclosed pit between the rails, from which the under sides of the cars may be inspected through shatterproof glass windows; a pit on each side of the track from which the sides of the wheels and trucks may be conveniently seen; and an inspection house on each side of the track, from which, through a window at the proper level, a carman may inspect the car roofs, running boards, grab irons and brake wheels. The inspection station will be described in more detail in a subsequent issue of *Railway Age*.

When a defect in a car is detected at the inspection station, talk-back loud-speakers are used to announce the fact. If it is decided that the car should be repaired it is allowed to roll down the incline but is switched to complete repair-track facilities which include

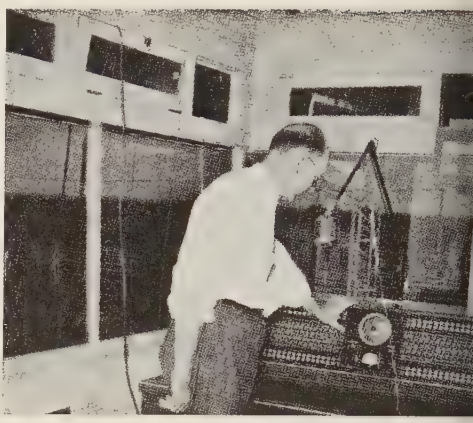
five concrete repair platforms totaling 8 000 ft. in length.

One of the most notable features of the yard is its network of communications. This includes a teletype system linking the general yardmaster's office, the retarder yardmaster's tower, the three control towers, and the office of the Pacific Fruit Express, located at the yard. Switch lists are transmitted by teletype

The car retarder on the incline has 28 air-activated cylinders, and is the largest of the yard's nine retarders.

from Grand Island, Neb., for trains from the east, from Hastings, Neb., for trains from the south, from Cheyenne, Wyo., for trains from the west, and from Julesburg, Colo., for trains from Colorado. These switch lists are received in the general telegraph office at North Platte on typing reperforators and are retransmitted to various points in the yard.

An intercommunication system for the general yardmaster's use includes 110 two-way, talk-back Racon speakers located at advantageous points throughout the yard. In connection with this system there are 23 Western Electric paging speakers divided into four groups covering various sections of the yard.



G. R. Van Eaton, supertintendent of telegraph of the Union Pacific, inspects the intercommunication system control panel in the tower atop the general yardmaster's office.

A separate intercommunicating and paging system is operated from the retarder yardmaster's tower. This system embodies four Racon speakers, two at each end of the classification yard, and four Western Electric paging speakers, two of which are also placed at each end of the classification yard.

Interior of the retarder yardmaster's office. Removing consist from teletype machine is E. H. Bullock, assistant signal engineer of the Union Pacific.

Five men stationed in the pit and houses here shown inspect all parts of the cars as they move up the approach to the crest.

A third intercommunication system provides a hook-up between the general yardmaster's office, the retarder yardmaster's tower, the three control towers for the classification yard, the locker rooms, and the inspection pit on the approach to the crest. This system utilizes Racon speakers and amplifiers furnished by the Electronic Communications Equipment Company.

Two radio stations.

Eight Diesel switch engines at the yard are equipped with Motorola two-channel two-way radio apparatus. For communicating with these locomotives there are two fixed radio stations. One of these, KBVH, is located in the retarder yardmaster's tower, with a triple-skirt antenna mounted on the top of the tower. In the other fixed radio station, KBVI, the controls are located in the tower of the general yardmaster's office. The antenna for this station is mounted on a 100-ft. light tower about 200 ft. from the yard office, and the radio equipment is contained in a steel case at the base of the tower. By manipulating a switch on the panel of the radio set in each locomotive the set may be made to operate on the frequency of either of the radio stations, depending on whether the locomotive is working under the supervision of the retarder yardmaster or the general yardmaster.

Before the new yard could be built it was necessary to acquire 213 acres of additional right-of-way. It entailed the building of nearly 6 miles of new main-line tracks and about 51 miles of additional yard tracks.

The yard was built under the jurisdiction of W. C. Perkins, chief engineer of the Union Pacific. The installation of the signals, power switch machines and retarders was under the direct supervision of L. D. Dickinson, general signal engineer, now retired, and his successor, T. W. Hays. G. R. Van Eaton, superintendent telegraph, had charge of the design and installation of the communication facilities.

The general yardmaster's office building with its multi-windowed tower. Structure at far end contains locker room for trainmen.

[624 .32 (73)]

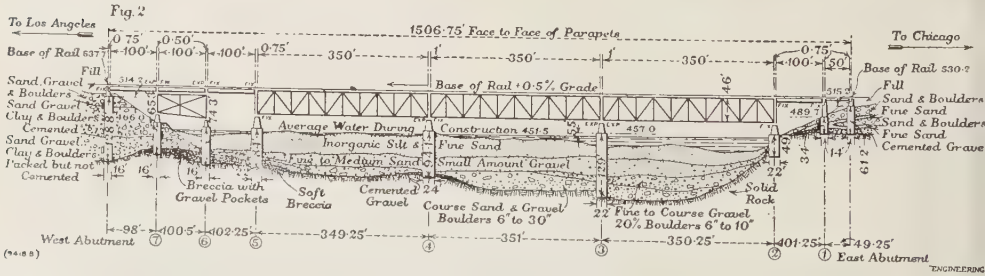
Railway bridge over the Colorado River.

(From the *Engineering, December 10, 1948.*)

The new double-track bridge, built for the Atchison, Topeka and Santa Fe Railway Company, over the Colorado River, near Topock, in the State of Arizona, is of particular engineering interest as its construction

which was reached involved the use of an a pressure of 52 lb. per square inch. Th is 2 lb. above the safety-code limit and speci permission had to be obtained from t Arizona Industrial Commission for the wo

Fig. 1. — General view of new and old bridges.



involved the sinking of a pneumatic caisson to a depth of 125 ft. below river level. The pier, of which the caisson formed the foundation, is believed to be the deepest ever built in this way in the United States. The depth

to be carried out. The new railway bridg takes the place of a cantilever bridge whic has now been converted to serve as a roa bridge. The new structure, of which th main members are three 350-ft. deck trus

spans, is situated 400 ft. upstream from the old bridge; the new location has eliminated a sharp curve which existed on the western approach to the old structure. The two bridges are shown in the photograph reproduced in Fig. 1, the new bridge being in the foreground.

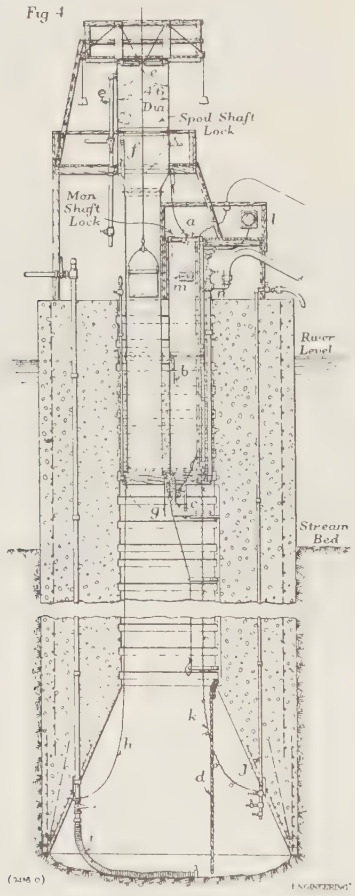
The old cantilever bridge, which was built in 1890, was a single-track structure and originally consisted of a 990-ft. cantilever through-truss which included a 330-ft. suspended span. At the time it was built it was the largest railway cantilever bridge in the United States. Owing to the increasing weight of locomotives, it was found necessary to strengthen the bridge in 1901, and nine years later, in 1910, a pier was built at the centre of the suspended span. This can be seen in Fig. 1. Even with this addition, however, as locomotives increased further in weight, additional strengthening measures had to be taken, and for a number of years train speeds have had to be restricted to 10 miles per hour and double-heading forbidden. The bridge has now been presented to the California and Arizona State Highway Departments and has taken the place of a nearby road bridge of light design.

The total length of the new double-track bridge is 1 506-75 ft., as shown in the elevation given in Fig. 2. Starting from the west abutment, on the left, it is made up of three 100-ft. deck girder spans, three 350-ft. Warren-type deck truss spans, one 100-ft. deck girder span, and a 50-ft. rolled beam span. It is carried on seven reinforced-concrete tapered piers and the two abutments, the piers and abutments being each supported on two reinforced-concrete cylinders, spaced from 24 ft. to 38 ft. apart, and carried down to solid rock. The tops of the foundation cylinders extend 5 ft. above normal river level and are connected by 10 ft. deep web walls, the bottoms of which lie 5 ft. below river level. The cylinders for the different piers are of various diameters, the range being 14 ft., 16 ft., 22 ft. and 24 ft., as shown in Fig. 2.

Fig. — 3. Temporary timber trestle.

For sinking the foundation cylinders, a temporary timber trestle, 1 700 ft. long, shown in Fig. 3, above was built across the river. This carried railway tracks on which travelling cranes operated. The portal crane on the left in Fig. 3 is working on No. 3 Pier, the deepest of the four main piers. The cylinders of Pier No. 1 were sunk by

open excavation, but for the others pneumatic caissons were used in the latter stages of sinking. For the river piers, sheet-steel piling was driven to form closed areas inside which open excavation was carried out. For Pier No. 3, which, as will be seen



from Fig. 2, was situated in the deepest water, piling 60 ft. long was used. Open excavation for the north and south cylinders of this pier was carried to depths of 100 ft. and 115 ft., respectively. The reinforced-concrete cylinders were formed inside steel caissons which had cutting edges made up of an 18 in. by

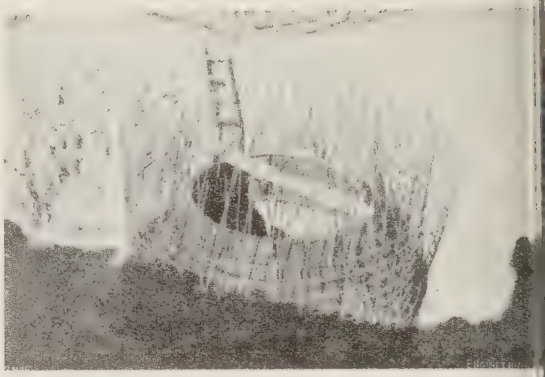


Fig. 5. — Reinforcement at bottom of caisson.

3/8 in. steel plate and a 6 in. by 6 in. by 1/2 in. angle. A section of one of the main cylinders is given in Fig. 4, and some of the stages in construction are illustrated in Figs. 5 to 8. Fig. 5 shows the assemblage of reinforcing steel above the cutting edge before the outside steel form was added; Fig. 6 shows the cylinders of Pier No. 2 under construction inside the cofferdam, the cylinder on the right-hand side being ready for placing the concrete. Fig. 7 shows Pier No. 6 in the foreground and concrete being placed from a bottom-dump bucket handled by a crane. Fig. 8 shows the same piers, those on the

Fig. 6. — Caisson cylinders under construction; No. 2 Pier.

Fig. 7. — Placing concrete with bottom-dump bucket.

left having reached the stage at which further sinking will be carried out under air pressure; the cylinder on the right is in an early stage and the cutting edge is being built up.

The lower part of all cylinders had an 8-ft. diameter central shaft through which excavated material was removed as sinking proceeded. This is shown in Fig. 4. When the depth had been reached at which open excavation was no longer possible, the cylinder was built up with two 3-ft. diameter internal shafts, as shown in the figure, the 8-ft. diameter central shaft being blocked off. The air-lock structure was then built; this is shown under construction on the left-hand cylinder in Fig. 6. The right-hand 3-ft. diameter shaft of Fig. 4 served for the entry and egress of the workmen and the left-hand shaft for the removal of spoil. The air-lock arrangements can be followed from Fig. 4. When men are to enter the shaft, the top door *a* is open and door *c* closed; the men pass into the shaft by means of a ladder on the right-hand side. There is a stop-cock at door *a*, and when the men are in the shaft this cock is closed and door *a* is pulled into the closed position by the lock operator by means of the rope shown. The foreman of the gang then gradually opens a pressure stop-cock at door *c* and when the pressures above and below this door are equalised the door opens and the men enter the working chamber. Steel rungs fixed to the inside casing from an access ladder leading to the top of the working chamber and the latter part of the descent is made by the rope ladder with steel rungs, *d*. When men leave, this cycle of operations is reversed, the door *c* is pulled closed by a rope when the men are on the landing platform. It is held in position by the pressure below as soon as air is released from the shaft above. Door *b* is a standby and is not employed in normal operation.

When the empty spoil bucket is to enter the left-hand shaft, door *f* is closed and the top door *e* is open so that the bucket can be lowered into the lock chamber by its crane. Door *e* is then closed and pressure raised in the chamber until it is equal to that in the shaft. Door *f* is then opened and the bucket, which has a capacity of 4 cubic yards, is lowered into the charging position. The lower door *g* is not used in normal operation; its purpose is to shut off the 3-ft. diameter shaft from the pressure chamber when any necessary repairs are being carried out; alternatively it enables the space between

Fig. 8. — Cutting edge being placed for No. 6. Pier.

doors *f* and *g* to be used as a lock chamber if the upper chamber is out of commission. When the bucket has been loaded in the working space, the gang foreman pulls the cord *h* which operates a whistle at the surface. The bucket is then raised into the lock chamber, door *f* closed, and pressure in the chamber released. The upper door *e* can then be opened and the bucket lifted away. The vertical 4-in. diameter pipe shown set in the concrete on the left-hand side of tools; the electric cable furnishes a lighting service in the working chamber. The instrument *l* near the top of the main shaft is a recording pressure gauge, and the instrument assembly *m*, in the air lock, consists of a pressure gauge and a clock for the use of the foreman when raising or lowering the pressure in the chamber. As already mentioned, a pressure of 52 lb. per square inch was used in the working chamber, the pressure air being supplied through pipe *n*, which was

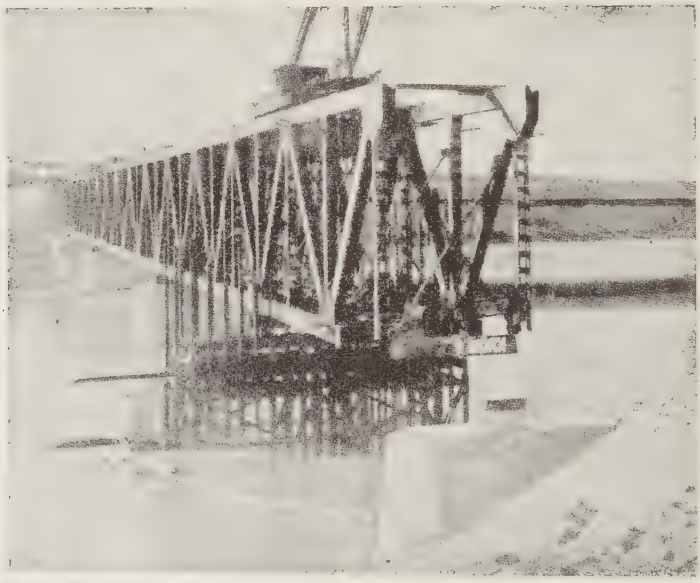


Fig. 9. — Erection of superstructure in progress.

Fig. 4 is connected to the rubber hose *i* at the lower end. This pipe is used for the discharge of fine material and water, the pressure in the working chamber forcing them up the pipe and out to discharge.

Other features of Fig. 4 which may be referred to are the 2-in. diameter high-pressure pipe *j* and the electric cable *k*. The pipe is connected to the high-pressure air supply on the river trestle and, at its lower end, has valve connections for pneumatic connected by a rubber hose to a supply line on the trestle bridge. Working shifts for the men employed were limited to 30 minutes when the full pressure was in use. The work was carried out without any fatal accident.

In their final positions, the cutting edges of the caissons were supported on three or four stools of solid rock into which they penetrated at least 6 in.; test holes were driven in the bottom of the excavation to verify

the extent of the rock bases. Excavation was then carried some 2 ft. below bearing level and concrete was poured under the exposed parts of the cutting edge to ensure full bearing all round. For the deep cylinders at Pier No. 3, filling concrete was laid to a depth of about 1 ft. above the cutting edge by a gang working under air pressure, the concrete being lowered through the spoil shaft in 4-cubic yard buckets. This procedure was necessary because the 52 lb. air pressure did not completely exclude water from these deep shafts and it was necessary to continue to draw-off water until the concrete seal was well above the cutting edge. The remainder of the concrete was then poured through the air locks two cubic yards at a time. For the other cylinders, the whole of the concrete was poured through the air locks, as the bottom of the excavation was perfectly dry.

The sinking of the caissons was carried out as a continuous operation for 24 hours a day, the whole of the work being completed in 350 days. A total of 50 to 60 men were employed in the gangs working in the excavator chamber. The size of the air lock permitted a gang of eight men to enter or leave at one time. As the summer temperature in the desert country in which the bridge is situated at times rose to 120 deg. F., arrangements were made to cool the air pumped into the working chamber by placing the 5 in. air-supply pipe extending along the timber trestle in a trough of cold river water.

The erection of the bridge was carried out from the west end. After the three 100-ft. approach spans were in place, the west 350-ft. Warren truss span was erected on timber falsework. The river below this span is shallow, the ground surface being exposed in many places, as shown in Fig. 2. The members making up the truss were handled by a crane travelling on the previously-erected approach spans. Part of this crane can be seen in Fig. 9, which shows a later stage in the erection procedure when two of the 350-ft. spans were in place. The second and third main spans were built by cantilevering out from a previously-completed span, utilising an intermediate steel falsework below the middle point of the span. This is shown in Fig. 9. The falsework consisted of 40 12-in. × 65-lb. steel piles braced together with a fabricated steel cage. The calculated load on the steel piles during erection was 60 tons.

The two trusses forming the main members of the 350-ft. spans are 46 ft. deep and are set 28 ft. apart, centre to centre. Each of the two railway tracks is carried on four 33-in. wide-flange beams, weighing 220 lb. per foot. There are two expansion shoes on Pier No. 3, eliminating horizontal forces on this tallest pier. The eastern span is fixed at Pier No. 2, and the middle span at Pier No. 4, which carries an expansion shoe for the west span, which is fixed at Pier No. 5 These arrangements, and the positions of the expansion shoes for the shorter spans, are indicated in Fig. 2. The ballasted bridge deck, 28-ft. wide, is of creosoted timber and the rails are carried on 7-in. by 9-in. by 9-ft. hardwood sleepers. There is a 2-ft. wide walkway on each side of the bridge. The total weight of steel in the structure is 6 500 short tons and 17 900 cubic yards of concrete were laid in its construction. The planning and erection of the bridge were carried out under the general superintendence of Mr. G. W. Harris, chief engineer of the Atchison, Topeka and Santa Fe Railway Company, and its design was under the direction of Mr. R. A. Van Ness, the company's bridge engineer. The Kansas City Bridge Company were the contractors for the substructure, and the American Bridge Company for the fabrication and erection of the superstructure.

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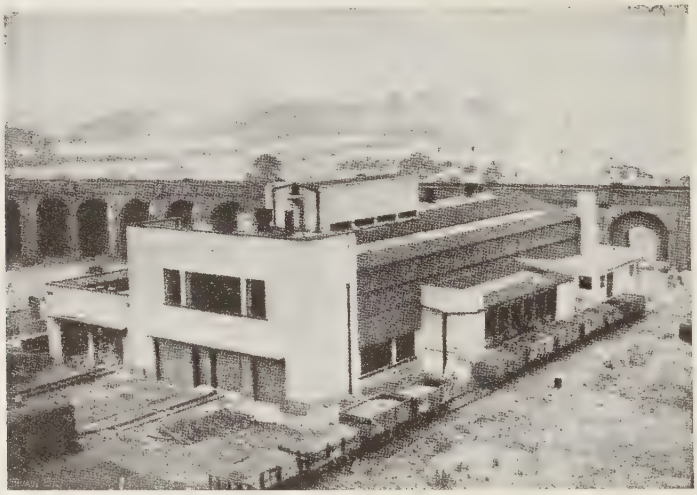
The Rugby locomotive testing station.

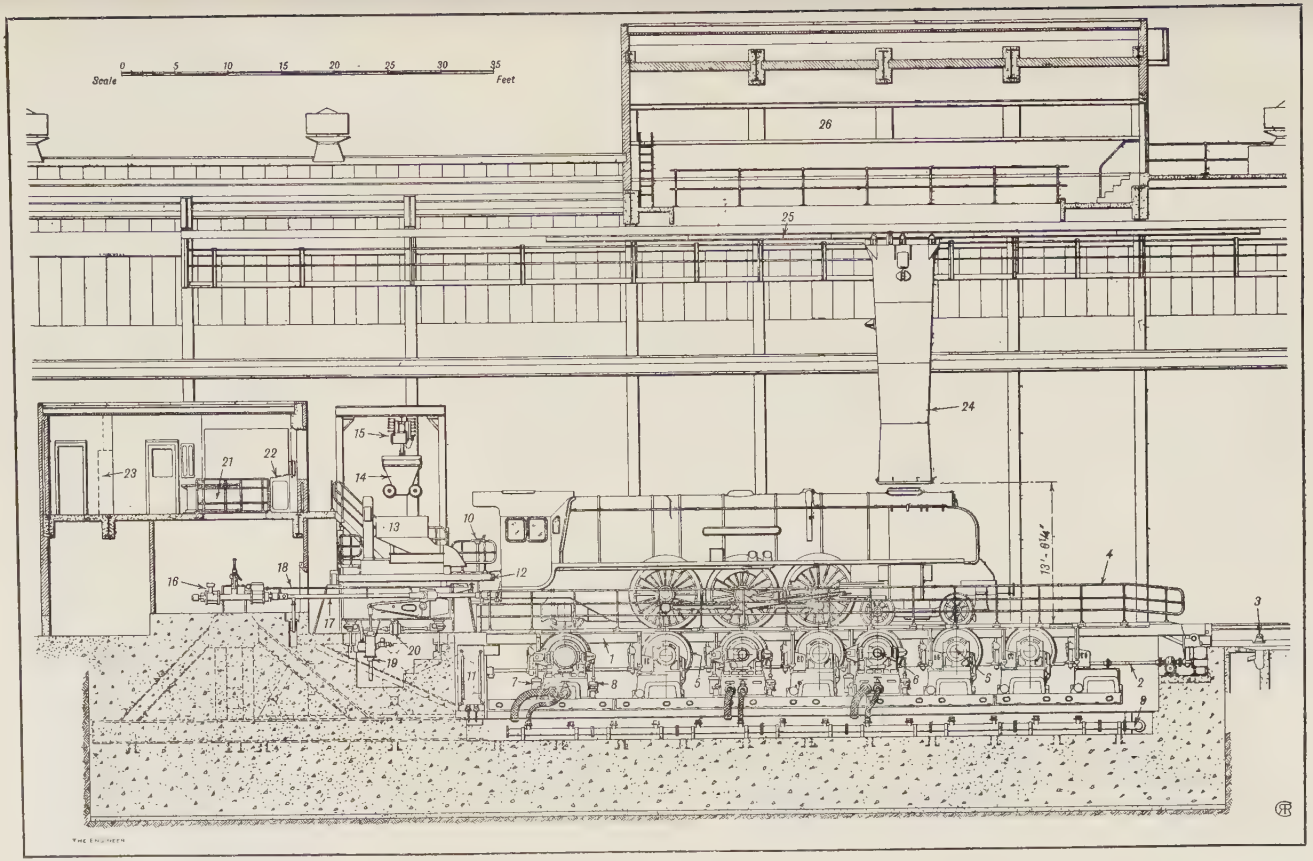
(From *The Engineer, November 12, 1948.*)

The locomotive testing station of British Railways, which was opened at Rugby on October 19th, largely owes its inception to the late Sir Nigel Gresley, the chief mechanical engineer of the former London and North Eastern Railway Company. It was in his presidential address to the Institution of Locomotive Engineers in 1927 that Sir Nigel first proposed the construction of a National Locomotive Testing Station. The following year, on the recommendation of the Department of Scientific and Industrial Research and the four main line railway companies, a committee was formed to examine the possibility of establishing such a station. As a result of the industrial slump, the report of this committee was shelved until 1934, when a new committee was formed and the proposal revived. Eventually, in 1936, the London Midland and Scottish Railway and the London and North Eastern Railway Companies decided to proceed jointly with the construction and equipment of a testing station, the other original participants in the scheme having found it impossible to contribute towards the cost.



Locomotive Test House.

In 1937 there was established a superintending committee, composed of directors and chief officers of both railway companies, and a management committee, consisting of the two chief mechanical engineers. These two committees were formed to prepare final designs, to construct and in due course to manage the testing station. At the same time a superintending engineer, Mr. R. C. Bond, was appointed to control all the activities of



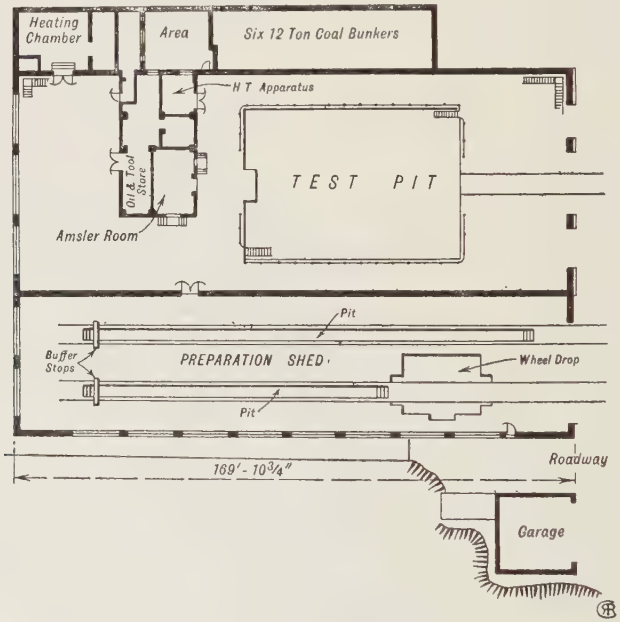
1. Locomotive lifting platform.
2. Platform lifting jack operating shaft.
3. Lifting platform withdrawing rollers.
4. Removable gangway.
5. Roller units.
6. Dynamometers.
7. Dynamometer torque measuring gear.
8. Dynamometer dashpot.
9. Dynamometer water supply ring main.
10. Boiler feed control.
11. Injector overflow measuring tank.
12. Firing platform.
13. Coal hopper on weighing machine.
14. Portable coal truck.
15. Travelling hoist.
16. Amsler dynamometer.
17. Drawbar.
18. Mediating gear.
19. Damping dashpot.
20. Dashpot carriage elevating gear.
21. Amsler recording table.
22. Dynamometer control desk.
23. Instrument panel.
24. Chimney.
25. Chimney sliding plate.
26. Smoke corridor.

the station and to be responsible to the management committee, consisting of Sir Nigel Gresley and Mr. (now Sir William) Stanier.

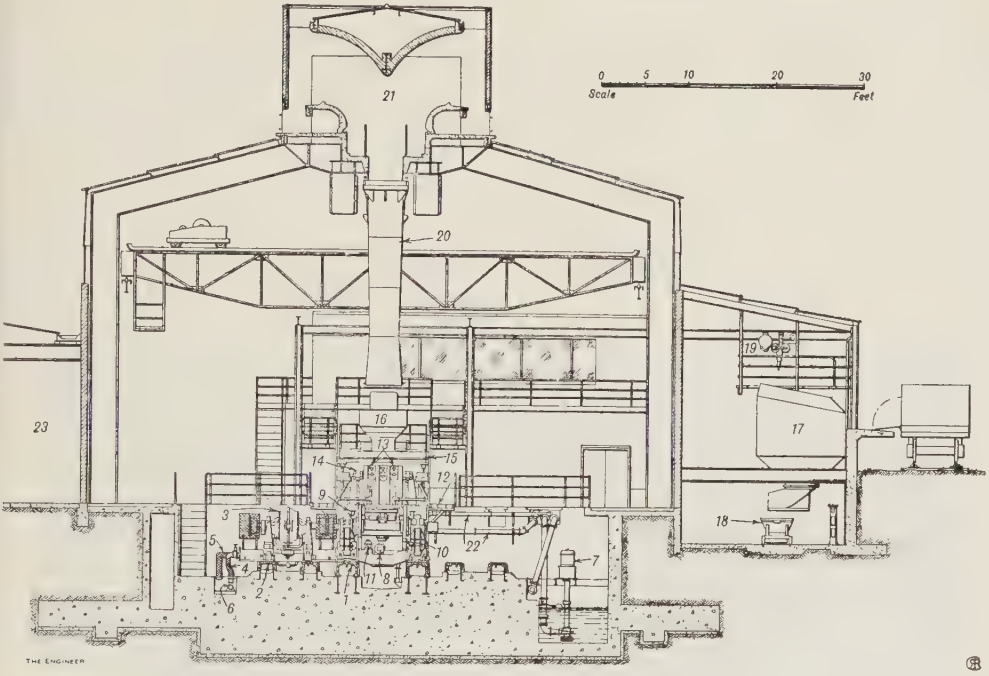
A design of testing plant capable of complying with the requirements and specification of the management committee was evolved, in collaboration with Heenan and Froude Ltd., of Worcester. It incorporated the results of experience gained by the railway companies in the design and operation of locomotives and by the manufacturers in the design and utilisation of many kinds of dynamometer test plant, including some previously constructed for absorbing the power of locomotives.

The site selected for the station was adjacent to the motive power depot and the locomotive repair shop of the L.M.S. Railway Company at Rugby. This site, in addition to being easily accessible from the L.M.S. main line, was reasonably accessible from London and also most of the main line locomotive works of either company. An additional advantage was that the main line of the Great Central Section of the L.N.E.R. passed close to the site at a higher level and a direct connection to the station from the line was envisaged.

At the outbreak of war, in 1939, work on the construction of the buildings was well advanced, but early in 1940 work was suspended for the duration of hostilities. In 1944 the project was revived and the late Mr. D.W. Sanford was appointed superintending engineer. When, early iu 1948, Mr. Sanford relinquished his post owing to ill-health, he was succeeded by Mr. D. R. Carling, the present superintending engineer. The original cost of the project was estimated to be upwards of £150 000 but we understand that it has actually been in the region of £220 000, as a result of the increased cost of



Planst of te house



1. Roller soleplate track.
2. Dynamometer soleplate track.
3. Dynamometer.
4. Dynamometer water inlet.
5. Dynamometer water outlet.
6. Dynamometer water supply ring main.
7. Hotwell pump.
8. Roller unit traversing motor.
9. Roller alignment indicator bracket.
10. Roller cleaning water sprays.
11. Lubricating pump.
12. Removable gangway.
13. Safety links.
14. Buffers.
15. Firing platform.
16. Coal hopper.
17. Coal bunker.
18. Coal truck.
19. Travelling hoist.
20. Chimney.
21. Smoke corridor.
22. Boiler feed supply pipes.
23. Preparation shed.

Cross section of Test Plant.

material and equipment following the war.

The testing station is built on a site of just under 8 acres and there is ample space for the extension or erection of new buildings if they are required at a future date. The disposition of the main buildings can be seen in the accompanying illustrations. The main structure incorporating the test house, preparation shed, and an annexe, is 171ft long by 130ft wide. The test house itself has a width of 66ft and the preparation shed, which runs along one of its sides, is 41ft wide. The annexe incorporating coal bunkers, boiler room, &c., has a width of 20ft and a length of some 120ft. The main structure has a welded rigid steel frame, with a brick-filled front wall, in which are set large wooden sliding doors. The roof is extensively glazed to provide good natural lighting in the building, and the protected metal covering on the remainder of the roof

is continued down the side walls to a point where it meets brickwork surrounding the lower portion of the structure. Towards one end of the building and over the centrally disposed test bed a large concrete smoke chamber is built into the main roof structure.

A smaller administration building is situated far enough from the main building to prevent the transmission of noise and vibration when locomotives are undergoing tests. This building houses, in addition to the administrative offices, a chemical laboratory and drawing-office.

Locomotive on test.

The test bench

The bench foundations in the test house consist of a grid of heavy steel girders embedded in a reinforced concrete block, 103ft long, from 17ft to 41ft wide, and from 6ft to 17ft thick. This foundation weighs in the region of 3 000 tons and special measures have been taken to isolate it with compressed cork slabs from the main structure to avoid the transmission of vibration to the surrounding area. The pit, which is lined with white glazed tiles, is 46ft wide, 66 ft long, and just over 8ft deep.

Running along the full length of the pit are three pairs of parallel tracks, each consisting of five 12ft long machined soleplates. These soleplates are rigidly bolted together and locked to the longitudinal girders in the main foundation of the test bench.

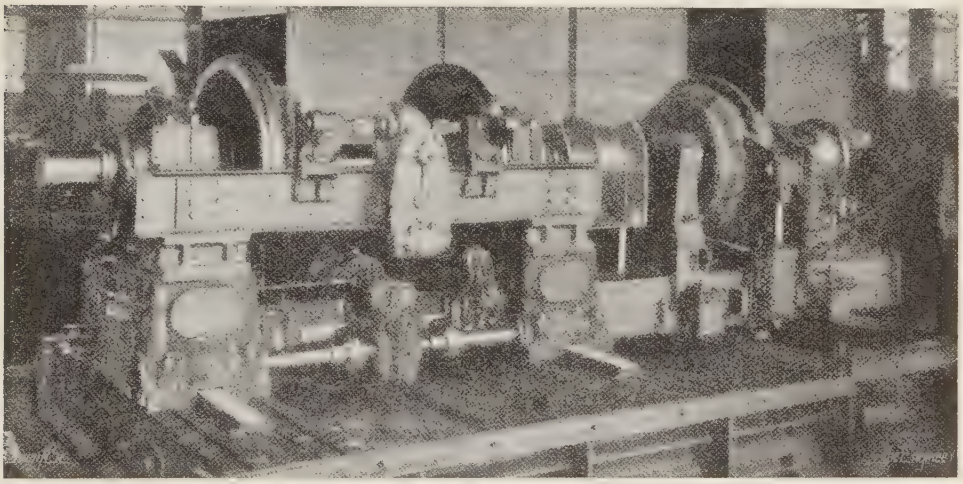
Roller units.

The central pair of tracks carries seven roller units, each comprising a pair of pedestals connected by a heavy bridge piece. A space unit, not fitted with rollers, has been installed for use at a future date should it be needed. These roller units, which can be spaced along the track according to the wheel arrangement of a locomotive, are each designed to bear a maximum axle load of 30 tons. It is considered that this load is sufficient to satisfy any foreseeable increase in the size and weight of British locomotives. The two 57in rollers on each unit have their tyres machined to correspond with a standard rail contour. They are rigidly keyed to an axle and carried on roller bearings, which are designed to take any axial thrust when under load. The axle-bearing blocks are set in slides on the

pedestals and rest on large rubber pads, intended to give a certain amount of play and reduce the transmission of vibration.

The test bed is of sufficient length to accommodate locomotives having wheelbases up to 42ft long. If at a future date it is required to increase the capacity of the plant to take longer locomotives, or those having more than seven axles, the spare roller unit can be put into service. This unit will make possible an increase of 5ft in the effective length of the test bed. In order to reduce the tendency which the driving wheel of a locomotive may have to slip on a roller if the latter becomes dirty and greasy, means of cleaning the rollers are incorporated on the units. This cleaning gear consists of a pad, which is pressed by a lever against the roller whilst a spray of water is directed on to the rim.

Pinions in the base of each pedestal engage the teeth of racks cut along the full length of the tracks. The two pinions on each unit are keyed on a common axle, which is driven by a centrally disposed 3 H.P. reversible electric motor through a friction clutch. This pinion mechanism is used to traverse the units along the test bed, when positioning the rollers. The traversing gear motors are controlled by push buttons arranged in a panel on the side of each unit. To simplify accurate initial setting of the rollers, a vernier scale is built into the full length of the track. With this scale, once the position of the rearmost axle of a locomotive is set in respect to the drawbar, the positioning of the roller units can be carried out by dead measurement.



Roller and dynamometer unit.

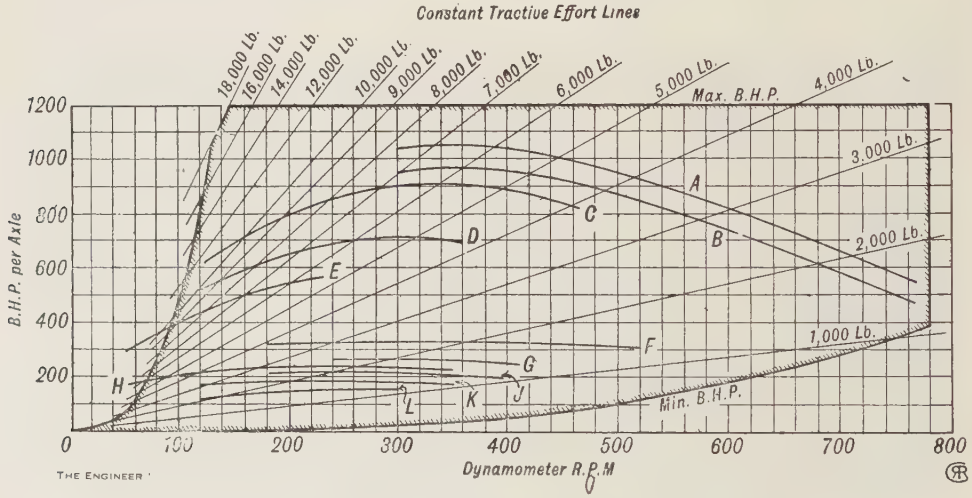
Dynamometers.

The two outside sets of tracks of soleplates carry the Heenan and Froude dynamometers or hydraulic brakes, each of which is coupled to a roller unit. Owing to their size it was found necessary to arrange three dynamometer units on one side of the roller unit track and two on the other, the dynamometers on each side serving alternate rollers. With this arrangement the units can be set sufficiently close together to accommodate locomotives having axles spaced as closely as 5ft. The

dynamometers are coupled to the roller units by heavy bridge pieces, bolted between the base members, and their shafts are coupled to the roller axles through Elcard couplings.

The dynamometer at the innermost end of the bed is double-ended and when necessary can be removed and recoupled to a roller unit at the top end of the test bed, to suit the locomotive driving-wheel arrangement. Thus, jacked up automatically by spring-loaded rollers set in housings at each corner of their bases. In this condition they are easily drawn along their tracks by the roller units.

Each of the dynamometers is capable of absorbing up to 1 200 H.P. and has been designed for working with the rollers running at peripheral speeds up to a maximum of 130 miles an hour. The minimum speed at



A. Four and six-coupled express passenger.
B. Eight-coupled express passenger.
C. Six-coupled mixed traffic.
D. Eight-coupled freight.
E. Ten-coupled freight.
F. L.N.E. « D.16 » and L.M.S. No. 2 passenger.
G. L.M.S. 0-4-4 tank.
H. L.M.S. standard No. 4 freight.
J. L.M.S. 2-6-2 tank.
K. L.N.E. 0-6-2 tank.
L. L.M.S. « G2 » 0-8-0.

Dynamometer power absorption characteristics.

five-coupled locomotives having one leading and one trailing, or two leading axles, can be tested on the bed by rearrangement of one dynamometer, or a locomotive with two trailing axles by rearrangement of two dynamometers.

The dynamometers are moved along their tracks complete with the roller units. For traversing purposes, their holding-down bolts are loosened and the dynamometers are then

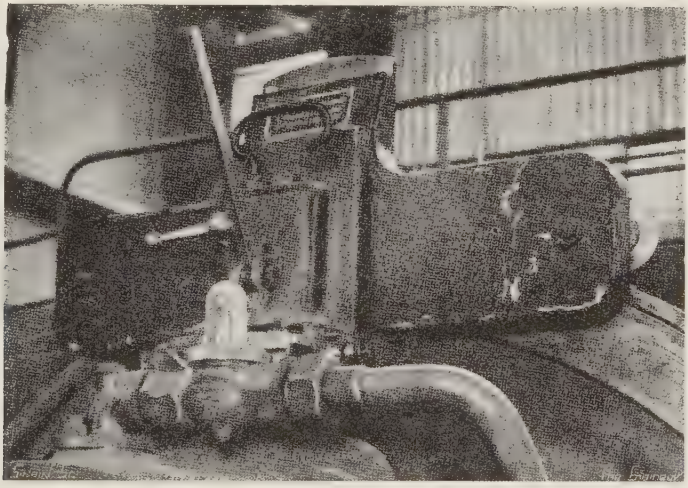
which the full power of a locomotive can be absorbed depends on the size of the locomotive and the number of coupled wheels. A large passenger engine can be tested down to 19 m.p.h. and a freight engine down to about 15 m.p.h. We reproduce a diagram on which is shown the horsepower which each dynamometer is capable of absorbing within the stated speed range. It will be seen from the power output curves

of the various standard types of locomotives which have been superimposed on this diagram that the plant will be capable of testing practically all existing types of engine in service in this country. The capacity of the plant is at present restricted to 4 500 H.P., but it is capable of being increased to 6 000 H.P. should the need arise.

Each individual brake is controlled from a desk in the control room, which is dealt with later in this article. The load on the dynamometers is governed by speed-responsive back-pressure valves on the water outlets; the effect of these valves is regulated by motorised needle valves. The general characteristics of the Froude dynamometers when fitted with this type of control gear are such that torque increases and decreases as a function of speed, and this provides the dynamometers with valuable self-governing properties, which assist in the maintenance of steady speed, irrespective of any adjustment of the controls.

On the casing of each dynamometer is fitted an arm, which transmits the torque load to a spring, the deflection of which is transmitted electrically to the control room. The torque transmitted by each pair of driving wheels is indicated in the control room as the tractive effort at each axle. As each dynamometer can be controlled individually or the whole group collectively by means of a master control, the load on all axles can be increased or decreased together, or the individual load on each of the axles can be altered separately. The torque measuring gear has been designed on the assumption that the tractive effort at any one driving axle will not exceed 8 tons. Water is discharged from the five brakes at the rate of 30 000 gallons per hour at about 140 deg. Fah., under full load, when the inlet temperature is in the region of 100 deg. Fah. To keep the water consumption within reasonable limits, it is passed through a cooler and recirculated, loss as a result of evaporation in the cooler being made up by an external supply.

Water is supplied to the dynamometers from a large main, which runs in a shallow pit round the testing unit, and, after circulation, flows back into a hotwell at one side of



Wheel setting device.

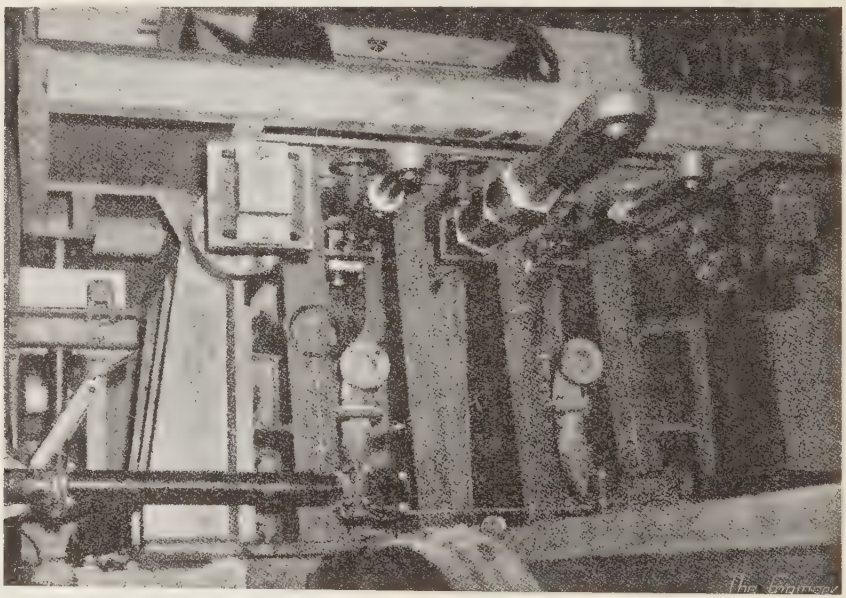
the pit. A motor-driven pump in the hotwell pumps the water to a Heenan and Froude water cooler, situated outside the rear wall of the test house. After cooling, the water is pumped for recirculation into a 1 000-gallon tank adjoining the boiler feed-water tanks on a platform at the rear of the control house in the main building. Any loss of water is made up in the dynamometer recirculation tank. The water mains are coupled to the dynamometers through heavy flexible armoured hoses, for which connections are provided at a number of points along the mains.

In order to eliminate the use of long, trailing cables to the dynamometer units for the electrical control and other connections, all the main cables between the control room and the test bench are enclosed in heavy ring-main conduits, fastened to the sides of the two outermost tracks. Spaced along the conduits are a number of junction boxes, into which short cables depending from the units can be plugged.

Locomotive platform.

Running across the pit above the roller units is a locomotive platform, which is designed to raise and lower an engine in respect to the rollers. This platform consists of two heavy beams rigidly braced to form a single unit, and supported on jacks situated adjacent to each of the units and at each end of the pit. A longitudinal shaft, which is driven by a 10 H.P. motor through a reduction gear at the outer end of the pit, is arranged to actuate all the jacks in unison. The platform is provided with rails on which run the flanges of the locomotive wheels, while the treads overlap the rollers.

Before a locomotive is placed in position on the platform, the roller units are first set according to the nominal distances of the



Drawbar, safety links and buffers.

locomotive axles by reference to the vernier scale. The locomotive is then backed on to the platform and coupled to the drawbar. The platform is then lowered and the position of each unit is checked and reset for each axle by means of a special device originally developed at the Vitry testing station of the French National Railways. This device, as can be seen in the illustration below, is carried on a baseplate, which can be fitted on brackets attached to each main bearing cap of the roller units.

It consists of a balancing beam, which is pivoted at its centre and carries small rollers at its outer ends. The device is first set with these small rollers resting on the wheel of the driven roller and an indicater pointer is set at zero. A lever projecting from the body of the instrument is then depressed to raise the beam vertically until the small rollers touch the rim of the locomotive driving wheel. Any deviation of the beam from the horizontal as a result of one roller touching the wheel-rim before the other is indicated by the pointer on a graduated scale. The combined dynamometer-roller unit is then moved the required amount to cause both rollers on the alignment device contact the wheel-rim at the same time, when the pointer will again register zero. When all the roller and dynamometer units are in their correct positions they are locked on their tracks.

The platform can then be lowered to leave the locomotive resting on the rollers in the testing position.

Drawbar dynamometer and damping dashpots.

When anchored in the testing position, a locomotive is prevented from running forward under the influence of its own tractive effort by a heavy drawbar. One end of this drawbar is connected to the locomotive and the other to a drawbar dynamometer by which the drawbar pull is both resisted and measured. As the tractive effort of reciprocating engines is non-uniform but fluctuates cyclically, the measuring apparatus, in the absence of contrary provision, would be liable to produce indications of a more or less violently fluctuating nature. To avoid this and to obtain a clearly defined indication of mean tractive effort, a powerful hydraulic damper is connected to the drawbar at a point as close as convenient to the locomotive, where the drawbar is articulated. Between this point and the hydraulic dashpots is interposed a bell-crank lever pivoted on Timken roller bearings. This lever causes the twin pistons of the dashpots to oscillate through an amplitude five times that of the drawbar.

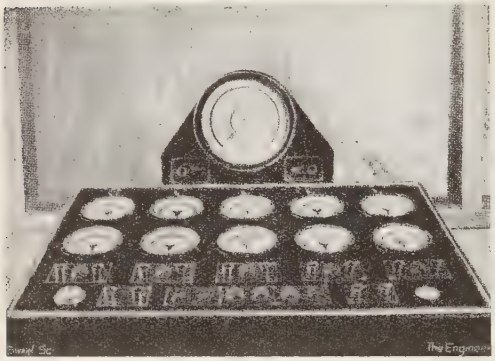
The twin dashpot pistons fit with small working clearance in cylinders filled with oil, which can escape from the high to the low-pressure chambers of the cylinders through orifices controlled by a motorised needle valve operated by means of push-buttons in the control room. Under the most onerous conditions of operation, a small amount of heat is generated by hydraulic friction and this heat is transmitted to circulating water through the medium of a heat exchanger having provision to measure the amount of heat given up.

The effect of the damping dashpot is to reduce very greatly the amount of longitudinal oscillation of the locomotive. The drawbar dynamometer is protected still further from the effect of such oscillations as remain by the interposition of cushioning springs, the deflection of which, due to the remaining oscillation, represents a small proportion of the deflection due to load.

The cradle in which the dashpot assembly is mounted is carried on screwed columns at each corner and a pair of jacks set centrally in the front and rear girders of the frame. These two jacks are connected through shafts and universal couplings to a motor in the centre of the frame. When it is required to adjust the height of the drawbar assembly in accordance with the height of the locomotive

dragbox, the nuts on the cradle support columns are run back and the jack motor operated to raise or lower the cradle.

The drawbar dynamometer at the innermost end of the pit was supplied by A. J. Amsler, of Switzerland, together with a recording table, on which is recorded the



Control desk.

peripheral speeds of the driving wheels, the tractive effort, the power developed and the useful work done by the locomotive. All of this information is recorded on a single sheet. This recording equipment is similar to that used on dynamometer cars on railways all over the world.

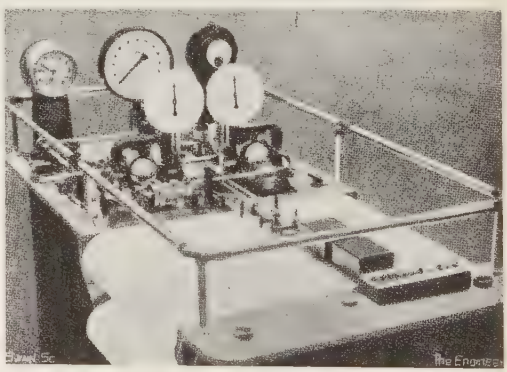
From the drawing reproduced on page 459 can be seen the arrangement of the dynamometer in respect to a locomotive on test. The dynamometer is designed to withstand a pull of 40 tons and consists of a cylinder employing oil as the working fluid. A piston in this cylinder serves to compress the oil when a load is applied and the pressure of the fluid is recorded as a measure of the pulling force exerted by the locomotive on the drawbar.

The hydraulic cylinder is mounted on a heavy vertical steel « H » beam, forming part of the anchorage described later.

The position of the piston is controlled by the amount of oil contained in the chamber between the piston and the end of the cylinder. This chamber can be filled with oil from a small high-pressure hydraulic pump or partly emptied to a sump, both functions being controlled by a mediating valve, the opening and closing of which is controlled by a rod connecting the valve to the frame of the locomotive.

If the locomotive under the influence of its own tractive effort moves forward, compressing the springs by which the drawbar is connected to the Amsler dynamometer, the mediating valve admits high-pressure oil to the appropriate chamber of the hydraulic cylinder and restores the locomotive to the correct testing position.

As can be seen in one of the photographs we reproduce, a safety link is situated on each side of the drawbar. These safety links are connected to the buffer beam of the locomotive and are anchored through heavy coil springs to posts projecting up from and integral with the foundation steel work. The links are of sufficient strength to prevent accidents in the event of a drawbar fracturing



Recording table.

during test. They have a degree of lateral movement before making contact with the springs, and are arranged to actuate limit switches if this movement exceeds $1/2$ in. in

either direction. By means of these limit switches an alarm is given in the control cabin if a locomotive running on the test bed moves more than $^1/_2$ in. from its predetermined position.

Heavy spring buffers are incorporated in the dashpot supporting frame to prevent the locomotive overrunning when being backed on to the bed.

The main anchorage is arranged so that the reactions due to drawbar pull and dynamometer torque are self-neutralising and are not transmitted to the surrounding foundations and buildings. It consists of a very heavy steel structure, the main longitudinal beams of which extend practically throughout the length of the foundation block and underlie the dynamometer sole plate. Near the rear end they carry the vertical beam of « H » section on which the Amsler dynamometer is mounted, together with its height-adjusting gear. This « H » beam is buttressed by heavy steel struts, strongly riveted and braced to the main frame, while the latter is supported upon a grillage consisting of steel channels arranged in pairs athwart it.

The proportions of the anchorage are such that, without relying on any assistance from the concrete block in which it is embedded, the deflection of a point lying on the longitudinal axis of the drawbar dynamometer under conditions of maximum drawbar pull, is not expected to exceed 0.020in.

Controlling and recording gear.

At the inner end of the test bed and built within the main test house, is a two-storied brick structure, which houses the control room, where the majority of the records are made. The ground floor of the control room building contains the drawbar cylinder and restoring apparatus. On the upper floor are the main control desk, the recording instruments, and the Amsler recording table. The control room is effectively soundproofed and has double doors and windows.

The control desk is situated in front of a window overlooking the whole of the test bench, and all its functions are push-button operated. The arrangement of this control desk can be seen in the illustration. A large dial on a vertical panel at the rear of the desk indicates the relative locomotive speed in miles per hour. Push-buttons on this panel operate the lubricating oil pumps on the testing units, and lights adjacent to the buttons indicate when the pumps are working and also show when oil pressure has fallen to a dangerous level.

Five sets of dials on the desk provide a continuous indication of the tractive effort at each of the dynamometers on the driving wheels and the relative speed. The dynamometer loading can be increased or decreased by means of push-buttons collectively or individually at each axle. A number of other functions are also controlled or indicated on the desk.

A constant record of the speed of a locomotive is obtained from a friction disc, which is spring-loaded against the tread of one of the driving wheels. The speed is transmitted by electrical means to the apparatus table in the control room.

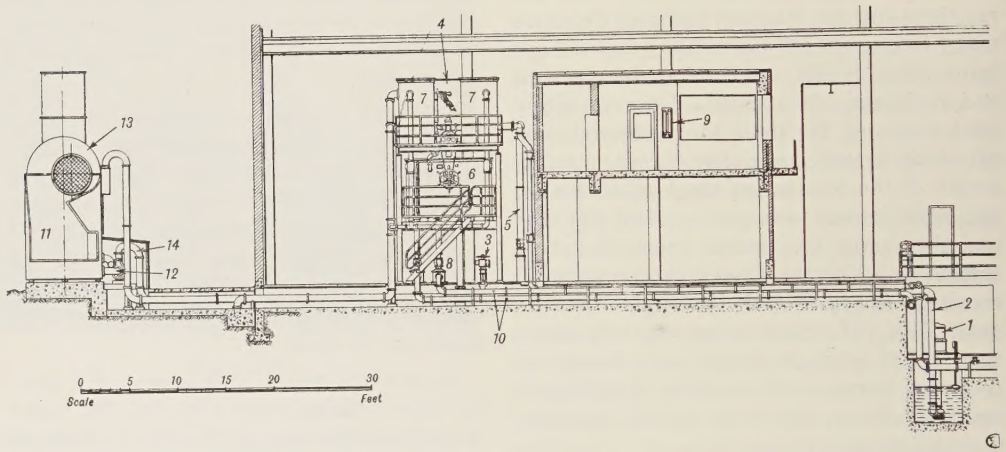
Up to fourteen different quantities can be recorded at the apparatus table by recording pens operating on a wide roll of paper, which can be set to move either proportionately to the distance travelled by the locomotive or proportionately to the operating time. The leading quantities measured and recorded on the paper are time, distance travelled, speed, drawbar pull, total effective work done at the drawbar throughout the duration of the test—an integration of drawbar pull in respect to the distance travelled—and drawbar horse-power—an integration of the work done at the drawbar in respect to time of running. The remainder of the pens are provided to incorporate on the chart a record of any other features it is required to register during a test. Set in the floor, adjoin-

ing the recording table, is a glass panel, through which the drawbar dynamometer can be kept under observation.

Instrument panel.

A panel of indicating and recording instruments, which covers one wall of the control room, has been supplied by the Cambridge Instrument Company, Ltd. On this panel four 10in. scale gas analysis indicators are fitted for showing the CO_2, oxygen, hydrogen and carbon monoxide content of the smokebox gases. For firebox gas and tube gas temperatures the panel is fitted with a two-point recorder with a range of 0 deg. to 2 700 deg. Fah., giving continuous records on a strip chart in different coulours; a twelve-point indicator with a similar range and having a multipoint switch for connection to the various thermocouples, and a similar indicator with eighteen points and a range from 0 deg. to 2 000 deg. Fah. For measuring the temperature of smokebox gases electric resistance thermometers are connected to a three-point recorder with a range of 300 deg. to 900 deg. Fah., and a twelve-point indicator with a similar range. Electric resistance thermometers measuring steam temperatures are connected to a three-point recorder with a range of 200 deg. to 900 deg. Fah., and two six-point indicators, one from 300 deg. to 900 deg. Fah. and the other from 200 deg. to 600 deg. Fah. Air and water temperatures are transmitted from electric resistance thermometers and shown on a twelve-point indicator.

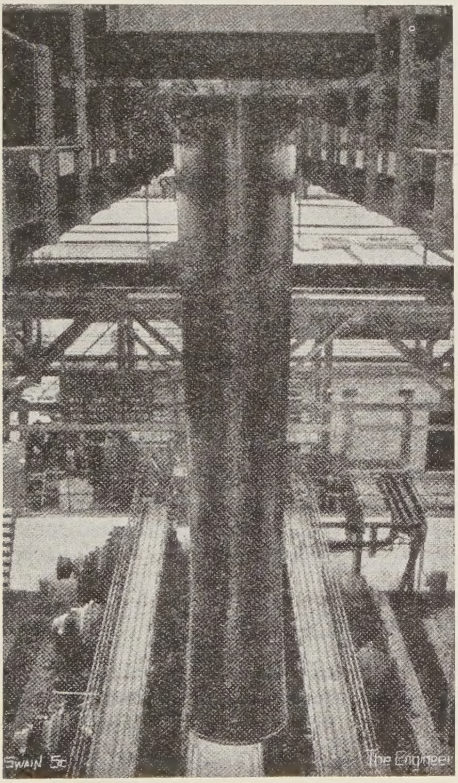
The high-pressure steam on a locomotive during testing is recorded on two double-pen recorders, fitted with twenty-four hour charts and ranging from 0 lb. to 400 lb. per



1. Hotwell pump.
2. Hotwell pump discharge to cooler.
3. Dynamometer water supply control valve.
4. 1 000-gallon dynamometer water tank.
5. Main water supply.
6. 2 500-gallon main boiler feed tank.
7. 500-gallon feed water tanks.
8. Boiler feed supply flowmeter.
9. Boiler feed tank telegauges.
10. Boiler feed supply pipes.
11. Water cooler.
12. Cooler pump.
13. Cooler fan.
14. Cooler pump discharge to dynamometer tank.

Feed water supply tanks and cooling equipment.

square inch; the pressures are shown on four dial pressure gauges of similar capacity. Low-pressure steam is recorded on an instrument with a range of 0 lb. to 20 lb. per square inch, which operates in conjunction with a Cambridge electrical pressure measuring unit. Two 8in. dial pressure gauges show the low-pressure steam. For indicating and recording smokebox and firebox and ashpan vacua double-pen recorders and dial draught gauges are fitted.



Movable chimney stack.

Additional equipment supplied by the Cambridge Instrument Company includes an outfit for testing thermocouples, comprising a workshop potentiometer and laboratory type rare metal thermocouple. There is also an outfit for testing electrical resistance thermometers, comprising a Callendar and Griffiths Brigde, a spot galvanometer and a laboratory electrical resistance thermometer element.

A group of connections on the bench can be wired to the control room and be used in conjunction with pyrometers when it is required to record temperatures at such points as the axle-boxes, etc.

Other Test House equipment.

The locomotive firing platform, arranged above the drawbar, is supported on an independent framework and can be adjusted in height through screw-jacks to suit different types of engines. The coal bunker on this platform is mounted on a weighing machine, the dial of which faces the control room and enables a constant check to be kept on the rate of firing. Coal is fed to the firing platform by an electric travelling hoist which transports small trucks. These trucks are filled directly from the steel bunkers in the annexe at the side of the test house. Six 12-ton bunkers in this annexe are filled from coal wagons on an adjoining line. Coal for firing the engines on test is drawn off into the supply trucks through bottom doors in the bunkers and the trucks are pushed along rails to a point where they are picked up by the travelling crane.

Feed water is supplied to locomotives on the test bench from a calibrated feed-water tank of 2 500 gallons' capacity, situated at the rear of the control room, through flowmeters and valves controlled by levers on the firing platform. Two 500-gallon tanks are installed on the supporting structure above the main 2 500-gallon tank. These smaller tanks are used alternately to replenish the main tank, one being filled whilst the other is being emptied. Two tun dishes set below the firing platform are arranged to catch the injector

water overflowing from a locomotive under test, and this water is passed through calibrated measuring tanks. The lay-out of the feed-water supply tanks and the water-cooling equipment at the rear of the control room can be seen in the drawing we reproduce.

In order to keep the test house clear of smoke and fumes whilst engines are running on the bench, a stack, suspended from the roof, is set over their chimneys. This stack, which opens out into a smoke corridor at the top of the building, is slung on rollers from overhead rails, along which it can be moved to suit different lengths of locomotives. A sliding plate, into which the top of the stack fits, moves with it and seals the smoke corridor from the interior of the building. Gases flowing into the smoke corridor impinge on curved fireback deflectors and pass out through large slots in the side of the structure. A protective concrete casing is built round all the steelwork in the corridor.

As can be seen in the drawing and photographs, walkways set at rail level extend across the pit on each side of the bench to provide access to the engine. If it is required to remove the locomotive platform over the pit to give access to the roller units, the boards between the approach extension units are removed and the platform can then be run out on rollers on the pedestal units, and a further series of rollers installed between the approach rails.

A 15-ton overhead travelling crane serving the whole length of the test house has been installed for plant maintenance purposes. A small workshop at the rear of the test house has been equipped for the manufacture of small fittings required for experimental purposes. This workshop also provides for minor plant and locomotive repairs when required.

The preparation shed adjoining the test house is still in course of construction. It has two tracks served by pits, and a 35-ton wheel shop at the entrance of one of the pits is capable of handling the driving wheels of the largest locomotives.

The detailed design and construction of the locomotive testing equipment were carried out to the requirements of the management committee by Heenan and Froude, Ltd., of Worcester, and we are indebted to this firm for a number of drawings and technical details, and to Mr. D. R. Carling, the superintending engineer, to whom we are indebted for much of the information given in this article.